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ON THE ORIGIN OF THE PHENOCRYSTS IN THE PORPHYRITIC GRANITES OF GEORGIA[1]

TABLE OF CONTENTS

Introduction.
Description of Individual Areas.
The Fayette-Campbell-Coweta counties porphyritic granite area.
The Hancock county porphyritic granite area.
The Baldwin county porphyritic granite area.
The Warren county porphyritic granite area.
The Greene county porphyritic granite area.
The Columbia county porphyritic granite area.
The Pike county porphyritic granite area.
The Fulton county porphyritic granite area.
Résumé:
Macroscopic features.
Microscopic features.
Chemical composition.
Genetic relationship of phenocrysts to groundmass.
Evidences of Intratelluric origin.
Evidence of contemporaneous origin.

INTRODUCTION.[2]

UNTIL quite recently, the idea has been prevalent among petrographers, that porphyritically developed minerals (pheno-

[1] Published by permission of the State Geologist of Georgia.

[2] The writer wishes to acknowledge his indebtedness to Professor A. C. Gill, of Cornell University, for kindly reading and criticising this paper in manuscript.

crysts) in intrusive igneous rocks were of intratelluric[1] origin. Indeed, as pointed out by Pirsson, no sharp distinction heretofore has apparently been drawn in the literature, between the origin of phenocrysts in intrusive and extrusive igneous rocks; indicating probably, that the porphyritically developed mineral or minerals were of the same origin in the two rock divisions here designated, and were formed at much greater depths than the place in which they are now found. The idea that phenocrysts in intrusive igneous rocks are not always of intratelluric origin, but have, in many cases, been formed *in place*, and are therefore contemporaneous in origin, with a part at least, of the other rock constituents, was advocated by Zirkel[2] in 1893; by Cross[3] in 1895; and more recently by Pirsson[4] and Crosby.[5]

Pirsson and Crosby are agreed in dissenting from the old and long-accepted theory, that appreciable or abrupt changes in the ratio of cooling and the viscosity of the magma, are essential elements in the development of the porphyritic structure — phenocrysts and groundmass — in intrusive igneous rocks.

A careful field study of the granitic rocks of Georgia, by the writer, during the seasons of 1898, 1899 and 1900, shows a number of extensive areas of coarse-grained porphyritic granites occurring within the limits of the Georgia Piedmont plateau. The distribution of the porphyritic granite areas is given on the accompanying map. The interior gradation or passage of the porphyritic facies, peripherally, into an even-grained coarse-textured non-porphyritic granite of the same mineral and chemical composition, is readily traceable in most of the granite areas.

[1] The term "intratelluric" is here used in the same sense as that given it by Pirsson in the Amer. Jour. Science, 1899, Vol. VII, p. 272, "meaning an earlier period and greater depth of the magma than that in which it came to rest."

[2] Lehrbuch der Petrographie, 1893, Vol. I, p. 737 et seq.

[3] Laccolitic Mountain Groups, U. S. Geol. Surv., Fourteenth Annual Report, 1895, p. 231.

[4] On the Phenocrysts of Intrusive Igneous Rocks, Amer. Jour. Science, 1899, Vol. VII, pp. 271–280.

[5] On the Origin of Phenocrysts and the Development of the Porphyritic Texture in Igneous Rocks, Amer. Geol. 1900, Vol. XXV, pp. 299–310.

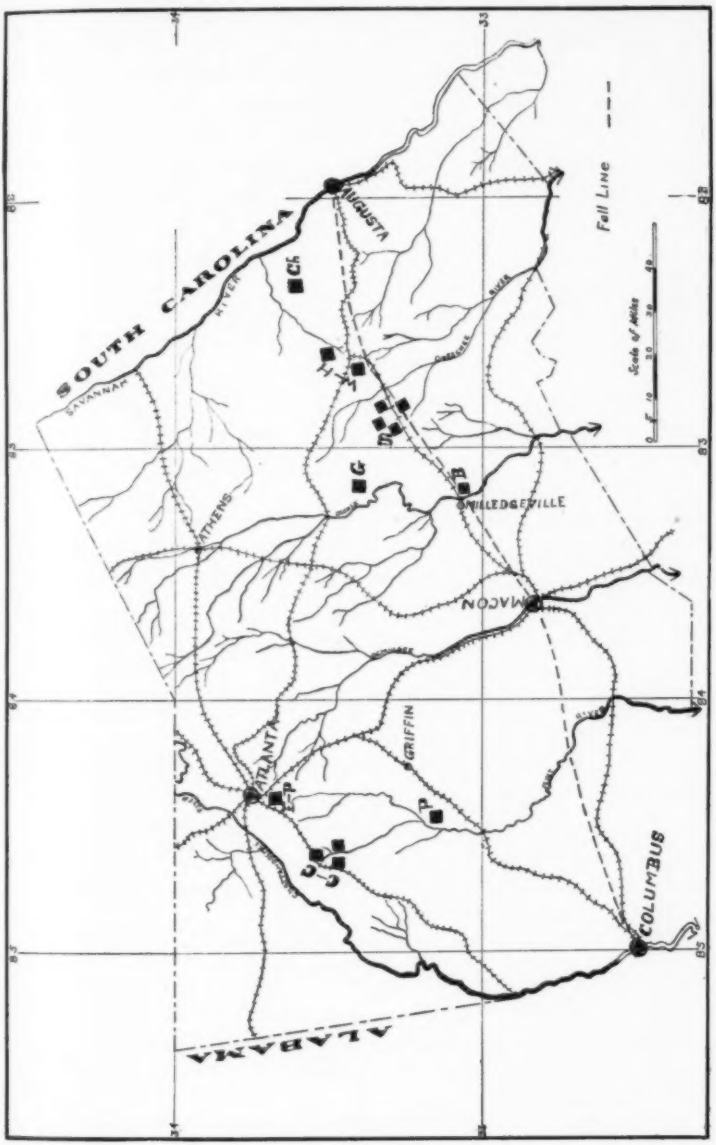

FIG. 1.—Map of Piedmont, Georgia, showing distribution of porphyritic granite described in the text.

The size, development and character of the phenocrysts in the porphyritic portions of the areas; and the gradation from one rock facies into another of the same composition shown in the same rock-mass, unquestionably point to contemporaneous growth with the groundmass constituents, and have, therefore, been formed *in place* and not at greater depths—intratelluric. In the present paper, it is proposed, therefore, to give a brief description and summary of the individual porphyritic granite areas; and to state the reasons for the belief in the contemporaneous origin of the phenocrysts with the groundmass constituents, based on a careful field and laboratory study of these rocks.

DESCRIPTION OF INDIVIDUAL AREAS

The Fayette-Campbell-Coweta counties porphyritic granite area.[1]—This area, marked C–C on the accompanying map, is thirty miles southwest from Atlanta and occupies contiguous portions of Campbell, Coweta and Fayette counties. The rock-outcrops are usually small and in the nature of bowlder and flat-surface masses. The exposures are most numerous in the vicinity of Palmetto and Coweta Stations on the Atlanta and West Point railroad, and near Line Creek in Fayette county. Specimens of the porphyritic rock collected from the outcrop near Line Creek in Fayette county are somewhat lighter in color than similar ones from the Palmetto-Coweta portions of the massif. The ratio of quartz to biotite in the Line Creek outcrop is visibly greater than in the Campbell-Coweta exposures, as indicated in analyses II and XI, p. 119. The rock, however, is generally quite uniform over the entire area. Several good contacts of the partially decayed porphyritic granite and mica-schist are exposed along the wagon roads and in the cuts of the railroad, traversing the area. The field relationships of the two rocks indicate, that the porphyritic granite is the younger rock; intruded into the overlying schist, and exposed subsequently by erosion.

The rock is a very coarse-grained porphyritic-biotite granite

[1] Eighteenth Annual Report, U. S. Geol. Surv., 1898, pp. 551–572.

of a medium, light to dark gray in color, according to the amount of biotite present. The extreme coarseness of texture renders the porphyritic structure less typically marked in this than in finer grained porphyritic rocks. The porphyritically developed mineral (feldspar) grades imperceptibly from very large, irregular, sometimes stout, tabular phenocrysts, into the smaller feldspars, making it difficult usually to distinguish between groundmass and phenocryst feldspars, except in extreme cases.

The feldspar phenocrysts vary from extremely irregular cleavable grains, anhedra, 30 by 30^{mm} to roughly idiomorphic crystals; tabular, parallel to the clinopinacoid (010), and twinned according to the Carlsbad law. Abundant inclusions of large irregular plates of biotite are readily visible in all the phenocrysts to the unaided eye. The phenocrysts are prevailingly allotriomorphic in outline and differ in this respect from those of the other areas described below. The feldspars are white in color, usually partially cloudy or opaque rather than limpid in appearance.

The biotite occurs as stout cleavable plates averaging 10–15^{mm} in size, occupying somewhat well-defined areas; is very dark in color, and highly lustrous. The quartz is present in large irregular colorless and smoky anheda, 4–5^{mm} in size, clearly outlined against the feldspar and biotite, from which it is readily distinguished.

Microscopic study of thin sections of the porphyritic granite confirms the macroscopic description, in affording no marked differentiation between groundmass feldspar and a part of the similar porphyritic constituent, or phenocryst.

The feldspar constituent is composed of the potash varieties, orthoclase and microcline, and a fair proportion of an acid plagioclase, which from its optical properties is near oligoclase. The presence of considerable lime in the analysis tends to corroborate this inference. The orthoclase usually shows good cleavage, and is separately intergrown with stringers of albite and quartz, in the form of microperthitic and micropegmatitic

structures. The potash feldspars and quartz of the groundmass are entirely allotriomorphic in crystal outline. The plagioclase feldspar occurs in roughly idiomorphic lath-shaped crystals characterized by the polysynthetic twinning, and, as a rule, afford very small extinction angles in basal sections.

The porphyritically developed minerals (phenocrysts) are composed of both orthoclase with numerous microperthitic structures, and microcline, usually inclosing inequidimensional anhedra of quartz, feldspar and biotite without definite optical orientation. The more basic inclusions, accessory apatite and zircon are also included in the phenocrysts.

A thin section of one of the feldspar phenocrysts from the Coweta portion of the area, shows the characteristic microcline structure, and contains abundant inclusions of irregularly bounded crystals of feldspar, quartz and biotite; several rounded disks or ovals of micropegmatitic intergrowths of quartz and feldspar, and prismatic needle-like inclusions of apatite and zircon (see Fig. 2.) A chemical analysis of fragments of carefully selected phenocrysts from hand specimens of the Coweta outcrops of the rock is given in XIa, page 119.

The biotite occurs as aggregated intergrown shreds with deep brown color, good basal cleavage and strong absorption, partially altered to chlorite and some epidote. The biotite is intergrown with occasional foils of muscovite, and sometimes shows good crystallographic boundaries. In addition to these, prismatic inclusions of apatite and zircon and a few grains of magnetite are present. The effects of dynamo-metamorphism are generally indicated to some degree in the rock by numerous fracture-lines and undulatory extinction common to the larger quartz and feldspar individuals.

Cubes[1] from the Rockingham, Richmond county, and Mt. Monroe, Iredell county, granite areas in North Carolina, very closely resemble in color, grain and texture the Campbell-Coweta-Fayette counties porphyritic granite, in Georgia. The

[1] Through the kindness of Dr. George P. Merrill, Head Curator, Department of Geology, U. S. National Museum, the writer was accorded access to the Tenth Census Collections of Building Stones in the Museum.

phenocrysts in the Carolina rock are usually allotriomorphic, occasionally idiomorphic, in crystal outline; and, as a rule, are large in size, and contain numerous plates of included biotite. A similar though darker colored rock, owing to a greater amount of biotite present, occurs in Aiken county, South Carolina. The

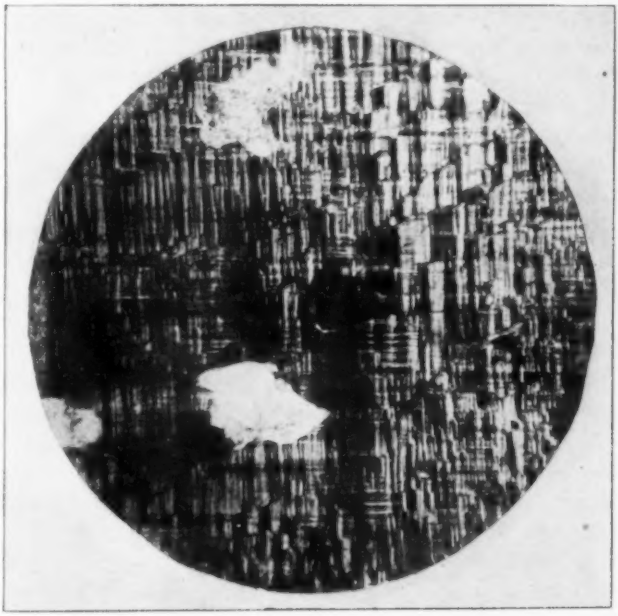

FIG. 2.—Photomicrograph of a phenocryst of microcline from the Coweta county porphyritic granite area, showing inclusions of quartz, plagioclase and biotite. The inclusions of plagioclase and biotite are considerably altered. Crossed nicols. Magnified 74 diameters.

porphyritic feldspars in the Aiken rock present the same characteristics as the phenocrysts of the Georgia and North Carolina porphyritic granites.

The Hancock county porphyritic granite area.—A coarse-grained porphyritic granite outcrops one quarter of a mile east of Sparta

depot, with the exposures more or less continuous from this point, for eleven miles, in a northeastwardly direction, along the Georgia railroad. The area lies near the merging of the crystalline rocks beneath the Coastal Plain sands and clays—the Fall-line (area marked S on the map). It is elliptical in shape with its longer diameter eleven miles in length, trending northeast-southwest. The granitic rock outcrops as bowlder and flat-surface masses, frequently containing four to five acres of exposed rock in one body.

The rock texture is prevailingly porphyritic, grading, in many cases, into a non-porphyritic, even-grained granite of the same mineral and chemical composition. In several quarries the rock shows in places a somewhat pronounced gneissoid structure. Some half dozen quarries have been extensively worked in various places over the area, within a few miles northeast of Sparta.

The rock is prevailingly a coarse-grained, medium gray, porphyritic biotite-granite. The phenocrysts are composed of the potash feldspars having a pronounced pinkish cast which disappears in thin section. They are flat tabular in crystal form, averaging 20^{mm} in length parallel to the clinopinacoid (010). Carlsbad twins of the contact type are common. The phenocrysts are further characterized by numerous inclusions of all the groundmass minerals.

The porphyritic feldspars are embedded in a coarse-grained groundmass of quartz, potash and soda-lime feldspars and biotite, with some accessory muscovite, chlorite, apatite, zircon, epidote and scattered grains of magnetite. Microperthitic structures are common to the potash feldspars. Micropegmatitic structures are less frequently observed, than in some of the other areas. The rock from the Sparta area differs from that of the Campbell-Coweta-Fayette counties area in containing less biotite, and hence, lighter in color; in the phenocrysts being idiomorphic instead of allotriomorphic in crystal outline, and usually of a pinkish cast rather than white in color. Microcline is, alike, variable for the two areas in thin sections of the rock examined from various

places. The relative proportion of the component minerals is, including all species present, feldspar > quartz > biotite.

Like the former area, the Sparta porphyritic granite is surrounded on all sides by mica-schist; but the great depth of residual decay of the granite and schist, renders exposures of the contact between the two impossible. The field relationships however, indicate, as in the above area, that the granite is the younger rock, intrusive into the then overlying schist.

The Baldwin county porphyritic granite area.—Large bowlder outcrops of a coarse-grained porphyritic granite occur three miles southeast from Milledgeville, the county seat of Baldwin. Like the Sparta area, the Baldwin county porphyritic granite mass is located near the line of contact (Fall-line) between the Piedmont crystallines and the Coastal Plain sediments (area marked B on the map).

Hand specimens of the granite from Baldwin county are indistinguishable from similar specimens of the Columbia county porphyritic mass, described below. The rock is a very coarse-grained porphyritic granite, composed of an aggregate of interlocking quartz and feldspars—orthoclase with microperthitic structures, microcline and plagioclase—with intergrown shreds of biotite. The rock varies in color from medium to dark gray. Both microcline and orthoclase occur in the groundmass and as porphyritically developed minerals. The phenocrysts measure in extreme cases 30–40^{mm} long and 5–10^{mm} broad. They are prevailingly idiomorphic in form; flat, tabular parallel to the clinopinacoid (010), and commonly twinned according to the Carlsbad law. Abundant inclusions of black biotite foliae are plainly visible to the unaided eye in the feldspar phenocrysts; while the microscope shows additional numerous irregularly bounded quartz and feldspar grains without definite orientation.

The groundmass is composed of an abundance of white opaque feldspars, slightly dark-colored smoky quartz, and biotite plates measuring 2–5^{mm} in diameter. The microscopic accessories are primary inclusions of apatite and zircon and scattered grains of magnetite, with some secondary muscovite, chlorite

and epidote derived from the alteration of the feldspars and biotite. Bent and curved filaments of rutile are quite abundant as inclusions in the larger quartz crystals. The effects of slight pressure metamorphism are evident in the lines of fracture and undulous extinction common to the larger quartz and feldspar individuals.

The Warren county porphyritic granite area.—Two somewhat extensive outcrops of foliated porphyritic granite occur in the middle eastern portion of Warren county, approximately ten miles from each other, in an almost east and west direction. These are known as the Holder's-Mill and Brinkley-Place granite masses, respectively, and marked W–H on the map.

The rock has a pronounced secondary foliated structure. The quartz and feldspar crystals are drawn out and inclosed between the biotite layers, forming at times distinct "augen" of the two light-colored minerals. The rock contains abundant black biotite plates arranged along somewhat parallel lines. The quartz and feldspar grains are greatly squeezed and mashed, and are more or less drawn out in directions parallel with the biotite layers, as a result of metamorphic action. The porphyritic granite of this area owes its foliated structure, therefore, to pressure metamorphism,[1] so common to many igneous rock masses in those regions subjected to mountain-building forces. Hence it is derived or secondary and not primary or fluidal.

The feldspar phenocrysts are composed principally of microperthitic orthoclase with some microcline 15–20^{mm} long; are white opaque to pink in color; contain numerous inclusions of biotite plates, and exhibit the usual habit of Carlsbad twins. They are prevailingly irregular in crystal outline and badly fractured from subsequent intense metamorphism. The porphyritic feldspars are embedded in a coarse-grained groundmass of quartz, feldspar and biotite. The groundmass feldspathic constituent consists of the potash feldspars with microperthitic structures, and

[1] Gregory has established, according to origin, three classes of gneisses, namely, metapyrigen-gneisses, clastic-gneisses, and fluxion-gneisses. See Quart. Jour. Geol. Soc. (London), 1894, p, 266; DALY, R. A. JOUR. GEOL. (Chicago), Vol. V, p. 780.

some laths of plagioclase near oligoclase. The large feldspar individuals (phenocrysts) contain inclusions of irregularly bounded crystals of quartz, biotite and other feldspar species. These inclusions are usually round, oval shape in outline. The quartz and feldspar anhedra are variously interlocked as fine and coarse-grained mosaics. The finer-grained mosaics of the two minerals

FIG. 3.—The Virginia type of foliated porphyritic granite near Chatham, Va.

represent the peripheral shattered portions of the larger feldspar and quartz crystals. Micropegmatitic structures, intergrowths of quartz and feldspar, are very common. Biotite occurs as grouped shreds and plates, deep brown to occasional green in color, with strong absorption and good basal cleavage. It is partially altered to a dark opaque chlorite and occasional crystals of slightly pleochroic and strongly double refracting epidote. A few scattered grains of magnetite are observed.

An outcrop, from which some rock has been quarried, of a similar dark-colored, foliated biotite porphyritic granite is found near Chatham depot, Pittsylvania county, Virginia. The feldspar phenocrysts are very large in size, 40–50^{mm} long, roughly

tabular in outline and twinned according to the Carlsbad law, and shows an abundance of large included biotite shreds (see Fig. 3).

Still a third exposure of granitoid rock showing a pronounced porphyritic texture in places, occurs six to eight miles south of the Holder's Mill-Brinkley Place area. It differs quite strongly from the Holder's Mill-Brinkley Place granite in the porphyritic texture being less strongly marked and finer grained; in containing less biotite, and is massive instead of foliated in structure. It further differs from the former area in containing a larger proportion of plagioclase, and a smaller percentage of microcline feldspars. Only one included grain of microcline was found in a number of thin sections studied of this rock. The feldspar phenocrysts are deep pink in color, 5–10^{mm} long, displaying the usual characteristic twinning and cleavage; and carry numerous inclusions of all the groundmass minerals.

The Greene county porphyritic granite area.—The Greene county porphyritic granite area, marked G on the accompanying map, includes at least 100 acres in the main granite outcrop, located ten miles south of Greensboro, in the southern part of the county. The main central exposure is in the form of a low flat domingmass with a roughened and irregular surface, and partially covered, in places, with a thick growth of cedars (see Fig. 4).

An even granular medium coarse-grained granite outcrops in bowlder form three miles south of Greensboro, and is continuous along the public highway from this point to the main porphyritic granite mass (see Fig. 5). The true granitic facies of the rock mass grades interiorly into the typical porphyritic granite facies. The even-grained granitic portion of the mass representing the outer or peripheral zone, indicates some variation in mineral composition, from place to place, along a north and south section. The zone nearest the porphyritic area, two and one half miles north therefrom, and showing absence of all trace of porphyritic texture, is a medium-grained biotite granite agreeing, microscopically, in mineral composition, and in chemical composition as well, with the porphyritic granite.

Five miles north of the central porphyritic mass are outcrops of a coarse but close compact-grained granite, containing only a very small amount of biotite. The feldspars show pronounced pink and greenish tints.

About four miles south of Greensboro, on the north side of Beaver-Dam Creek, is an outcrop of practically the same granite. The quartz is decidedly dark in color and of the smoky variety;

FIG. 4.—The Greene county porphyritic granite area.

the feldspars are flesh colored, and the rock contains but little mica.

The porphyritic facies of the rock consists of a coarse-grained, light-gray groundmass of quartz, feldspar and biotite, in which are embedded large, flat tabular feldspar phenocrysts. The porphyritic feldspars average 30–50^{mm} long and 10–15^{mm} broad; and indicate the usual elongation parallel to the clinopinacoid (010), and Carlsbad twinning. The phenocrysts are deep pink to perfectly white in color, and are usually cloudy and opaque in appearance.

A thin section of one of the phenocrysts under the microscope showed the feldspar variety, microperthitic orthoclase. The microscope further showed abundant inclusions of fairly large crystals of feldspar, twinned, in several cases, after the albite and Carlsbad laws; and allotriomorphic crystals of quartz and biotite with partial orientation with the (010) cleavage.

FIG. 5.—Bowlder outcrops of granite near central mass of the Greene county porphyritic granite area.

(Fig. 6.) As a rule, however, the inclusions show no definite orientation. The biotite inclusions are always sufficiently large to be visible to the unaided eye.

The ratio of phenocryst to groundmass is quite variable; the probable extremes being represented by the following estimated ratios; 1 : 1 and 2 : 1, with all gradations between. The individual mineral grains vary from a few millimeters to 5 and 6^{mm} in size. The arrangement of phenocrysts in occasional small portions of the mass is suggestive of fluxion structure.

The potash feldspars, orthoclase and microcline, are the porphyritically developed minerals. The orthoclase contains

numerous microperthitic structures. Plagioclase is somewhat abundant. Small-rounded disks or ovals of micropegmatitic structures are common. The larger feldspar and quartz crystals indicate slight peripheral shattering in some of the thin sections.

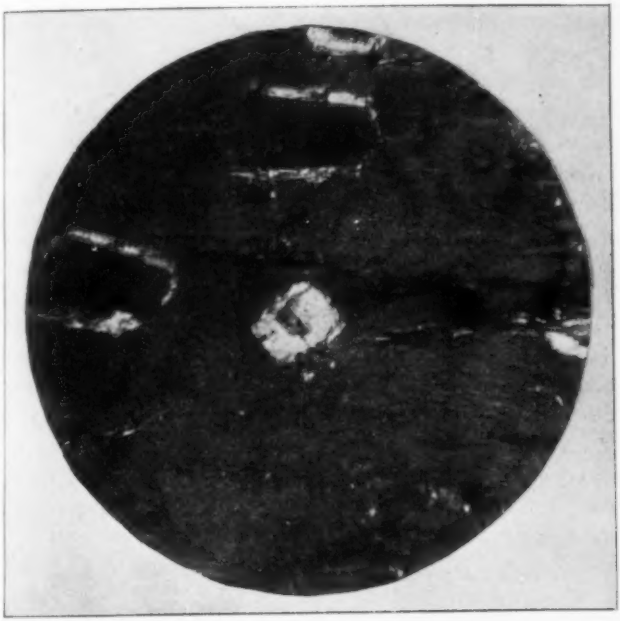

FIG. 6.—Photomicrograph of a phenocryst of microperthitic orthoclase from the Greene county porphyritic granite area, showing inclusions of quartz, plagioclase, biotite, and very small prisms of apatite. Crossed nicols. Magnified 74 diameters.

The biotite is considerably altered to chlorite and some epidote, and at times carries inclusions. Scattered grains of magnetite and prismatic inclusions of apatite and zircon are present in microscopic proportions.

The Columbia county porphyritic granite area—Heggie Rock.—This area, marked Ch on the accompanying map, is located near the Fall-line—contact between the Piedmont crystallines

and the Coastal Plain sediments—and a short distance west of the Carolina line.

One and three quarter miles east of Appling, the county seat of Columbia, is an outcrop of a coarse-grained porphyritic granite. The feldspars are slightly pink in color with a somewhat greenish cast in places. The phenocrysts measure 20–35^{mm} in length and 5–15^{mm} broad; and commonly show the contact type of Carlsbad twins.

Microscopically, the rock is composed of a coarse-grained groundmass of potash and plagioclase feldspars, orthoclase predominating, and quartz with biotite and occasional large plates of muscovite. The phenocrysts are large tabular microperthitic orthoclases. The anhedra of quartz vary in size and are badly fractured. Laths of polysynthetically twinned plagioclase are more abundant in this than in many of the other areas. Pegmatitic intergrowths of quartz and feldspar are sparingly present. The large feldspar phenocrysts contain abundant inclusions of the groundmass minerals, especially biotite and plagioclase.

The main porphyritic granite mass is one and one quarter miles further east. The rock outcrops as a large doming-mass. The porphyritic facies of the granite-mass is readily traceable peripherally into an even granular medium coarse-textured granite. The even granular facies of the rock mass is best exposed along the public highway three miles slightly east of south from Appling. Hand specimens of the rock from the two exposures cannot be distinguished from each other. The porphyritic feldspars in the principal exposure are larger but show the same idiomorphic and other microscopic tendencies, developed in the smaller one.

A thin section of one of the phenocrysts from the main outcrop showed the characteristic microcline structure, with numerous inclusions of irregularly bounded crystals of all the groundmass minerals. A chemical analysis of carefully selected fragments of phenocrysts from this rock, yielded the writer the results given in IVa, page 119.

The phenocrysts are embedded in a close and firm, but

coarse-grained groundmass of flesh-colored feldspars tinged a slight greenish cast, somewhat dark smoky quartz, and biotite. The porphyritic feldspar crystals make up nearly one half of the total rock. The feldspars are white and opaque rather than pink in color over the greater part of the exposure. This rock very closely resembles that from Greene county in the hand specimens. Here, as in the areas described above, the feldspathic constituent consists of the potash and soda-lime feldspars, with the potash varieties predominating. The porphyritic feldspars are chiefly orthoclase with some microcline, carrying inclusions of all the groundmass minerals. The included biotite shreds are visible macroscopically. Some of the largest plagioclase inclusions in the orthoclase phenocrysts carry, in turn, microscopic inclusions of quartz and other groundmass minerals. Twinning according to the Carlsbad and albite laws among the included feldspar species is commonly observed.

Biotite shows its usual characteristic optical properties, and is partially altered to chlorite and epidote. Muscovite is sparingly present as foils intergrown with the biotite. Sporadic accessory magnetite and apatite occur.

The Pike county granite area. — The Pike county granite area, marked P on the accompanying map, includes fifty or more acres of exposed flat-surface rock in the northwest part of the county. The porphyritic facies of the rock gradually passes into the even-textured medium-grained granite. Only a small proportion of this area, however, shows the porphyritic texture.

The rock is a medium-grained biotite granite, varying from even granular to porphyritic in texture, showing a partial gneissoid structure in places.

Microscopically, the porphyritic portions of the rock are composed of orthoclase phenocrysts in a coarse-grained groundmass of quartz, microperthitic orthoclase, microcline and some soda-lime feldspar, biotite, and occasional intergrown shreds of muscovite. Biotite is the chief accessory mineral. It is deep brown to yellow in color, with strong absorption, and is intergrown with some muscovite. It is more or less altered to dark

green opaque chlorite, and to a less degree, to a faint brown pleochroic epidote. Inclusions of prismatic apatite and zircon, and rounded disks or ovals of micropegmatitic structures are very common.

The phenocrysts consist of the potash feldspars, orthoclase and microcline, 10–30^{mm} long and 5–10^{mm} broad; tabular parallel to the clinopinacoid (010). Carlsbad twinning is common. Inclusions of biotite foliae equally as large as those occurring in the groundmass are very abundant in the phenocrysts. In addition to the biotite, they contain microscopic inclusions of irregularly bounded crystals of the interstitial quartz and feldspar.

The Fulton county porphyritic granite area.— The Fulton county porphyritic granite area, marked E–P on the accompanying map, is exposed in bowlder form over a large territory six miles south of Atlanta, in the extreme southern part of the county. The gradation from the interior porphyritic facies, peripherally, into an even-grained granite of the same color and texture, and having the same mineral and chemical composition, is more gradual and more strikingly shown in this than in any one of the previously described areas. Near the center of the granite mass the phenocrysts compose more than 50 per cent. of the entire rock, while near the transition zone—change of the porphyritic to the non-porphyritic texture—the phenocrysts are very sparingly present, not more than a half dozen are shown in a yard square of the rock surface. Near the center, the phenocrysts are prevailingly idiomorphic in crystal outline, while the allotriomorphic type of phenocryst characterizes the transition zone of the rock mass.

The rock consists of a medium coarse-grained groundmass of quartz, the potash feldspars, orthoclase and microcline, numerous laths of polysynthetically twinned plagioclase, biotite, and some muscovite, in which are embedded large potash feldspar phenocrysts. Accessory apatite, magnetite, and zircon; and the alteration products, muscovite, sericite, chlorite, and kaolin are noted. The microscope shows the feldspars and biotite to be considerably altered in some cases.

Microcline and orthoclase occur porphyritically developed, and measure 15 to 50^{mm} in length. The phenocrysts possessing idiomorphism usually display the Carlsbad habit of twinning, and are elongated in the clinopinacoidal direction.

A thin section of one of the phenocrysts showed the characteristic microcline structure and numerous inclusions of quartz, biotite, and the groundmass feldspars, which measure as much as one millimeter in size. Prismatic crystals of apatite and zircon, as inclusions in both the phenocryst and the included groundmass feldspars of the porphyritic crystal, are numerous. The zircon crystals are sometimes grouped in threes, much after the manner of penetration twins.

RÉSUMÉ

Since the individual areas have been described in some detail, it is important that a general summary of the essential features common to the several porphyritic granite masses be given. These can best be summarized under the two headings, *macro-* and *microscopic* features.

Macroscopic features.—The same textural and structural characteristics and relationships are generally developed in all the individual porphyritic granite areas. With the exception of the Warren (W–H) county area, the rocks are prevailingly massive, coarse-grained, porphyritic granites, varying, according to the proportion of biotite present, from dark to medium gray in color. The Warren county granite differs structurally from that of the other areas in possessing a marked foliated structure, resulting from dynamic metamorphism, which is accordingly secondary. Further evidence already mentioned of dynamic action in this rock mass is apparent microscopically. Evidence of a partial gneissoid structure is indicated in portions of several of the other areas, but, as a rule, the rock is generally massive.

Field study shows the development of the porphyritic texture in the interior of the rock masses, with the even-granular granitic facies having the same mineral and chemical composition forming the marginal or body portion. Gradation from

one rock facies into the other was not entirely clearly defined in all of the granite masses, owing to lack of exposures of the fresh rock, but could be easily traced in many. The feldspar phenocrysts are irregularly distributed through the coarse-grained groundmass without definite arrangement or orientation. The fluxion primary structure was not entirely evident in any one of the areas studied.

Microscopic features.— Microscopically, the rocks are as nearly identical as is possible for separate areas to be. They contain, in every case, the same minerals, both essential and accessory, in nearly the same proportions. They are composed of admixtures of the feldspars and quartz, in which lie stout plates of biotite. The relative amounts of the component minerals may be expressed as follows: feldspar, including all species present, >quartz>biotite. Biotite is the chief accessory and varies somewhat in quantity for the individual areas. In a number of the sections the biotite is intergrown with occasional foils of muscovite. The potash feldspar varieties of the groundmass predominate and are prevailingly allotriomorphic in crystal outline. Both orthoclase and microcline occur with the former in excess. The plagioclase crystals are roughly lath-shaped in outline, and, as a rule, afford small extinction angles in basal sections, which indicates an acid feldspar near oligoclase. The presence of considerable lime and soda in the analyses corroborates the inference. The orthoclase feldspar shows microperthitic intergrowths with a second feldspar, probably albite. In all the sections some of the feldspar crystals show a micropegmatitic intergrowth with quartz, which takes the form of rounded disks or ovals, and are not of the arborescent or radiate growth type.[1] There can be little doubt that this structure is primary in the porphyritic granites as a whole, affording evidence of simultaneous crystallization of the quartz and feldspar. The quartz occurs in irregular interstitial grains of varying size, and is very common in drop-like inclusions in the feldspars. Prismatic

[1] See ROMBERG in N. J. B. B.—B., 1892, Vol. VIII. MATHEWS, E. B.: JOUR. GEOL., 1900, Vol. VIII, p. 231.

inclusions of apatite are the most common of the primary accessories. Some zircon and a very little magnetite occur. More or less chlorite, some epidote and muscovite are present as constant secondary products from the alteration of the biotite and feldspars. In many of the sections, the effects of pressure metamorphism are frequent in the nature of crushing, lines of fracture, and undulatory extinction common to some of the larger quartz and feldspar crystals.

The potash feldspars are the only porphyritically developed minerals. The phenocrysts vary from allotriomorphic to flat tabular idiomorphic crystals in outline, in which the (001) and (010) cleavages are usually well developed, and are elongated in the clinopinacoidal direction. The usual habit of the simple Carlsbad twins prevails. The idiomorphic type of phenocryst greatly predominates over the allotriomorphic form. As a rule, the phenocrysts are very conspicuous, and are readily differentiated from the groundmass feldspars; although in the Coweta-Campbell-Fayette counties area (C–C) the phenocrysts and a portion of the groundmass feldspars seemingly grade into each other. The phenocrysts invariably contain inclusions of a majority of the groundmass constituents, some of which are visible to the unaided eye. The inclusions are distributed, as a rule, through the rock without regard to any definite arrangement or orientation.

CHEMICAL COMPOSITION

The marked uniformity in the mineral composition of the various porphyritic granites from the individual areas, suggests similar uniformity in chemical composition. The usual amount of free quartz common to this class of rocks; the abundance of potash feldspar, with somewhat increased amounts of plagioclase and proportionally small amounts of accessory minerals, indicate a normal percentage of silica and lime, an increased percentage of alkalies, and comparatively small amounts of iron and magnesium oxides. These inferences are well shown in the following analyses, made by the writer, in the laboratory of the State Survey. Attention is called in the table of analyses to the

prevailingly high percentage of soda in all of the rocks described above. In nearly half of the analyses, the soda is slightly in excess of the potash, and in the remaining ones it nearly equals or is but slightly less than the potash. This high range in soda is traceable, first, to the prevalence of microperthitic intergrowths of albite with the potash feldspars; next, to the amount of soda-lime feldspar present in the rocks; and, lastly, to the potash being replaced, in part, by soda in the straight potash feldspar molecule (analyses IVa and XIa).

GENETIC RELATIONSHIP OF PHENOCRYST TO GROUNDMASS

Evidences of intratelluric origin.—The evidences upon which the formation of phenocrysts at great depths and under conditions different from those of the groundmass constituents in igneous, intrusive rocks, rest have been adequately discussed by Pirsson[1] and are shown to be: (1) Contrast in size and crystal form of phenocryst to the groundmass constituents. (2) The fluidal arrangement, common in many cases, to the porphyritic minerals. (3) Irregularity of form, traceable to corrosion or resorption of the crystal (phenocryst) by the magma.[2]

These will be discussed in relation to the phenocrysts of the Georgia porphyritic granites under the next heading.

Evidences of contemporaneous origin.—The evidences favoring contemporaneous origin of the phenocrysts in the Georgia porphyritic granites may, for convenience, be discussed under (1) megascopic proofs: geologic or field observations; and (2) microscopic proofs: study of the thin sections of the rocks.

Both the macro- and microscopic characteristics of the Georgia porphyritic granites have been described in considerable detail under the individual areas above. Hence it is only necessary here to summarize and classify the facts pointing to a contemporaneous origin for the phenocrysts.

[1] Amer. Journ. Sci., 1899, Vol. VII, p. 278.

[2] IDDINGS, J. P.: Bulletin, Phil. Soc. of Washington, 1889, Vol. XI, p. 77.

TABLE OF CHEMICAL ANALYSES

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	IVa	XIa
SiO_2	70.90 1.181	70.88 1.181	70.24 1.170	69.77 1.162	69.48 1.158	69.37 1.157	69.17 1.152	69.13 1.152	67 62 1.127	66.31 1.105	63.65 1.060	64.64	64.40
Al_2O_3	15.86 .155	15.86 .155	16.78 .164	17.05 .167	16.64 .163	16.99 .166	16.47 .163	17.14 .168	16.29 .159	18.27 .179	20.46 .200	19 64	18.97
Fe_2O_3*	1.37 .008	1.77 .011	1.46 .009	1.60 .010	1.84 .011	1.99 .012	1.23 .007	1.52 .009	2.31 .014	2.51 .015	2.20 .013	0.37	0.37
CaO	2.15 .038	1.79 .032	2.00 .035	2.21 .039	2.32 .041	2.03 .036	2.02 .036	1.85 .033	2.37 .042	2.91 .052	3.28 .058	0.67	0.59
MgO	0.02 .001	0.93 .023	0.76 .019	0.99 .024	0.29 .007	0.84 .021	0.61 .015	0.79 .019	0.78 .019	1.22 .030	1.50 .037	tr.	tr.
K_2O	4.62 .049	4.64 .049	5.03 .053	4.08 .043	4.49 .047	4.54 .048	4.41 .047	5.49 .058	4.58 .048	4.09 .043	4.58 .048	10.00	11.40
Na_2O	5.05 .081	3.94 .063	3.70 .059	3.97 .064	4.74 .076	3.44 .055	4.89 .078	4.06 .065	5.42 .090	3.69 .059	4.75 .076	3.06	3.60
Igni	0.50	0.49	0.50	0.44	0.46	0.55	1.06	0.52	0.32	0.62	0.42	0.22	0.19
Total.....	100.47	100.30	100.47	100.11	100.26	99.75	99.85	100.50	99.69	99.61	100.84	98.60	99.52

* All iron was determined as Fe_2O_3.

I. Georgia Quincy Granite Company's Quarry, near Sparta, Hancock county.
II. A. J. McElwaney's place, near Line Creek, Fayette county.
III. Flat (Cedar) Rock, 9 miles west of Zebulon, Pike county.
IV. Heggie-Rock, 3 miles east of Appling, Columbia county.
V. Sparta Quarry, Hancock county,
VI. Mrs. L. N. Calloway's place, 3 miles southeast from Milledgeville, Baldwin county.
VII. The Moseley Quarry, 6 miles south of Atlanta, Fulton county.
VIII. Porphyritic granite area, 10 miles south of Greensboro, Greene county.
IX. The Charley Rocker Quarry, near Sparta, Hancock county.
X. Brinkley place, near Camak, Warren county.
XI. The J. R. McCollum place, near Coweta Station, Coweta county.
IVa. Feldspar phenocrysts from Heggie-Rock, Coumbia county.
XIa. Feldspar phenocrysts from the J. R. McCollum place, Coweta county.

The field observations include (1) passage or gradation interiorly from the porphyritic facies, peripherally into an even-granular, coarse-textured granite of the same mineral and chemical composition. The peripheral or border zones of the porphyritic granite masses, representing the granular facies of the rock, generally attain considerable widths in the Georgia areas, from which phenocrysts are entirely absent. (2) The general absence of definite (fluidal) arrangement or orientation of the phenocrysts in the groundmass. The Greene county porphyritic granite mass possibly affords, in places, the faintest possible evidence of the tabular phenocrysts having moved in a liquid magma, with partial definite arrangement or orientation. If these special parts of the area be accepted as indicative of flow structure, however, then we must also grant the contemporaneity in crystallization of the groundmass constituents for the same portions of the mass; for all of the other constituents, particularly biotite, are abundantly included in the phenocrysts of all parts of the area. The included biotite plates are equally as large as the same constituent in the groundmass. The other inclusions are microscopic in size and proportions.

The Brinkley-Place Holder's-Mill porphyritic granite has a pronounced foliated structure. This structure resembles in certain particulars, in places, the fluxion structure of some rocks, but in this case the foliation is shown to be secondary or derived — induced — and not primary or fluidal.

The phenocrysts are badly fractured and drawn out as "augen" between the inclosing groundmass minerals, roughly parallel in the direction of their longer diameters. Furthermore, the microscope indicates abundant squeezing and mashing and peripheral shattering of the quartz and feldspars, so characteristic of a secondary structure resulting from dynamometamorphism.

The microscopic evidence, favoring contemporaneous origin of the phenocrysts with the groundmass constituents, is chiefly that of prevailing abundance of all the groundmass minerals, as inclusions in the phenocrysts, for the areas studied. In every

case the biotite inclusions are readily distinguished megascopically.

The comparative abundance of inclusions[1] in the phenocrysts, and the form and size of the latter, suggest a rapid growth for the porphyritic crystals. The inclusions are not limited to and distributed through the outer zones of the phenocrysts, indicative of different periods in crystal growth with reference to the groundmass constituents, but, on the contrary, they are scattered through all parts of the crystal (phenocryst). The inclusions are grouped, with few exceptions, without regard to crystallographic lines or directions, and without uniform orientation with reference to the host and each other. No external evidence in the nature of crowding and pushing aside of the adjacent groundmass microlites during the growth and expansion of the phenocrysts has been observed, resulting in some cases, as mentioned by Pirsson,[2] in the resemblance to the flow structure.

The microscope, as a rule, fails to indicate, in the rock sections studied, rounding or irregularity in crystal outline of the original phenocryst resulting from a partial resorption or corrosion of the crystals by the magma in the Georgia areas.

Phenocrysts of roughly idiomorphic outlines — flat, tubular- and irregular-allotriomorphic forms — appear, with the former predominating in most of the areas. In view of confirmatory evidence, elsewhere stated in this paper, idiomorphism among the phenocrysts in the Georgia rocks could in no-wise be accepted as resulting from formation at greater depths and under entirely different conditions from the other constituents. In the absence of all other evidence it would be difficult to prove that form alone was a definite criterion favoring intratelluric origin. Pirsson[3] has shown that contrast in crystal form and size may very well be explained in an entirely different way.

[1] *Ibid.*, p. 80. [2] Op. cit., pp. 276, 277.

[3] *Ibid.*, pp. 278–280; see also CROSBY, W. O.: Amer. Geol., 1900, Vol. XXV, pp. 299–310.

The absence of (*a*) definite arrangement or orientation among the phenocrysts; (*b*) of phenocrysts from the border zones of the massif — gradation from an interior porphyritic facies peripherally into an even-granular granite of coarse texture and the same mineral and chemical composition; (*c*) the further absence of evidence of magmatic resorption or corrosion of the phenocrysts; and (*d*) the presence of abundant inclusions of all the groundmass constituents, characterizing the generally tabular phenocrysts of the Georgia porphyritic granites, fully justify the conclusion that the phenocrysts in these rocks were formed *in place*, and are not intratelluric in origin.

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CERTAIN PECULIAR ESKERS AND ESKER LAKES OF NORTHEASTERN INDIANA

NORTHEASTERN Indiana is traversed by a series of massive moraines of late Wisconsin age, the joint product of the Erie and Saginaw lobes of the Laurentide ice-sheet. The Erie ice invaded the region from the south of east, the Saginaw ice from the east of north. Thus the general directions of ice movement in the two were at right angles to each other. The Saginaw lobe was relatively feeble and withdrew from the region before the Erie lobe. Along their line of contact there is much confusion, but it is possible to correlate the moraines and to mark out with considerable accuracy the limits of Erie and Saginaw drift.[1] The region abounds in unusual features. Half-filled valleys and abnormal drainage lines, isolated knobs and morainic outliers, clusters and chains of lakes, kettles, and kames conspire with esker-like ridges to produce a type of topography and scenery which seems artificial and almost bizarre. The southwestern portion of Noble county presents forms which are, perhaps, best described under the name of eskers.[2]

On the line between the townships of Noble and Washington a system of ridges occupies about two square miles and surrounds the basin of High Lake. The most prominent member is a gravel ridge one mile long, extending east and west along the south side of High Lake. It is highest and broadest at the east end, where it surrounds and encloses an oval kettle whose bottom is at lake level. The sides of the kettle rise to 25 and 35 feet at the lowest points, and to 70 and 85 feet at the highest points, which are at the ends of the oval. The westward extension of the ridge has a height varying mostly between 50

[1] Eighteenth Report Indiana Geology, pp. 28, 84.

[2] The data for the maps, Figs. 1 and 2, were obtained with an aneroid and tape line, township, section, and farm lines, and the surface of the principal lake in each being used as bases.

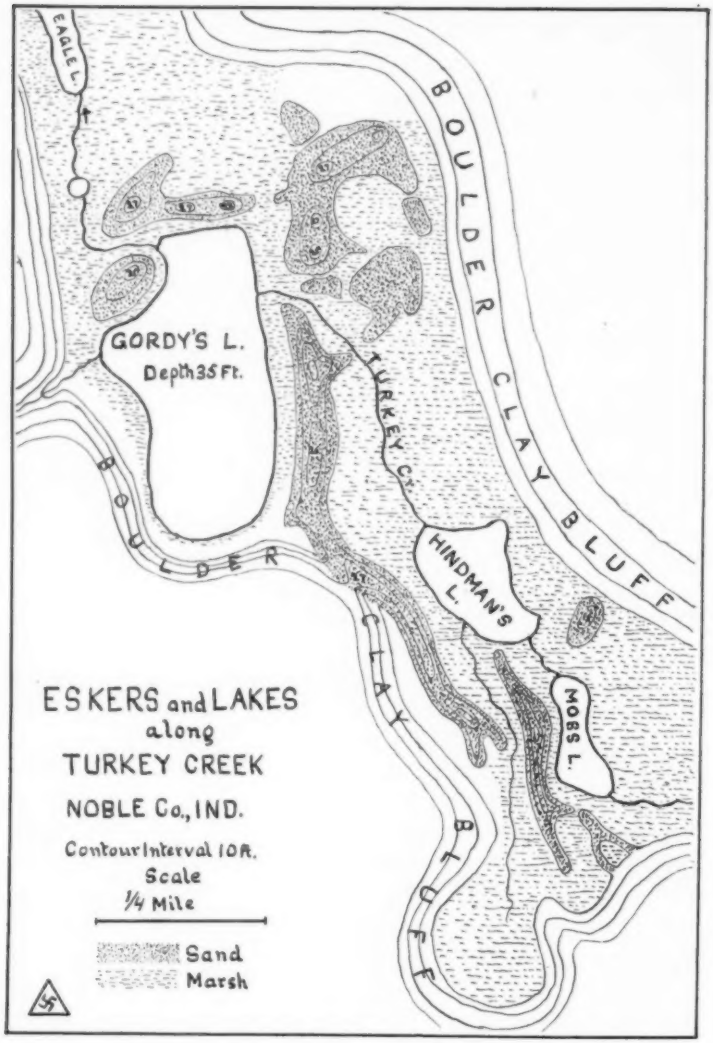
EAGLE L.
BOULDER CLAY BLUFF
GORDY'S L.
Depth 35 Ft.
TURKEY CR.
BOULDER
HINDMAN'S L.
MOSS L.
CLAY
BLUFF
ESKERS and LAKES
along
TURKEY CREEK
NOBLE Co., IND.
Contour Interval 10 Ft.
Scale
1/4 Mile
Sand
Marsh

FIG. 1.

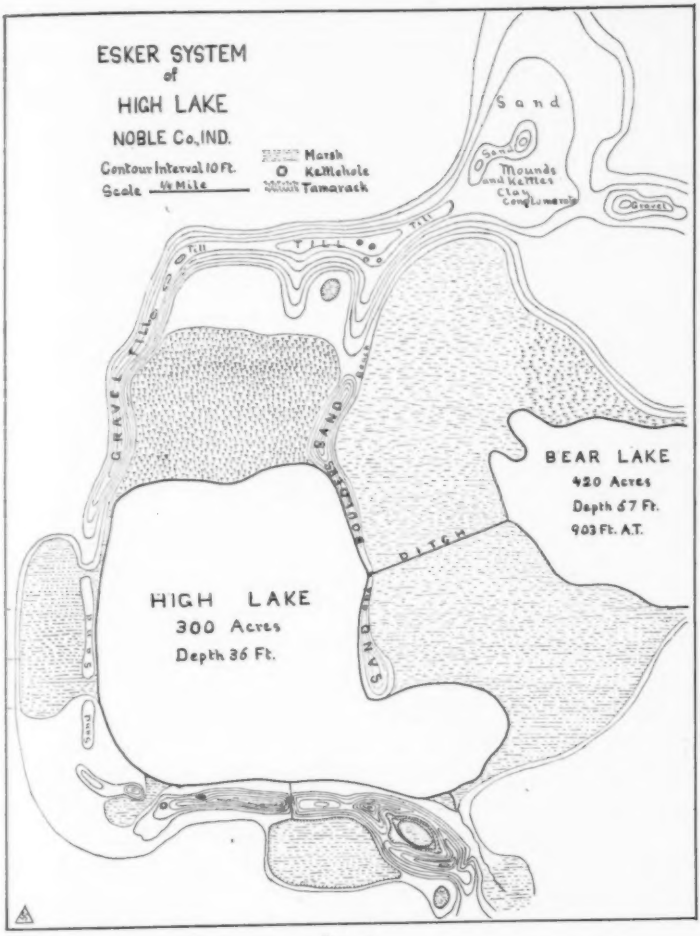
ESKER SYSTEM
of
HIGH LAKE
NOBLE Co., IND.
Contour Interval 10 Ft.
Scale ½ Mile
Marsh
Kettlehole
Tamarack
Sand
Mounds and Kettles
Clay
Gravel
TILL
GRAVEL
SAND
BEAR LAKE
420 Acres
Depth 67 Ft.
903 Ft. A.T.
DITCH
HIGH LAKE
300 Acres
Depth 36 Ft.
SAND
Pond

FIG. 2.

and 75 feet, falling to 30 feet at one point where a ditch has been cut through it. The crest is usually sharp, and the lateral slopes are as steep as the material will permit. A small pit which has been opened on the southeast slope shows coarse rounded gravel without definite stratification. The ditch is cut through sand and fine gravel. At one point near the lake shore there is an outcrop of cemented gravel. These are the only exposures, and since the whole ridge is covered by a heavy growth of oak timber, investigation is difficult.

A mile and a half to the north the gravel ridge just described is paralleled by an equally massive ridge of till which rises 50 to 60 feet above lake level and 30 to 40 feet above the general level of the country. It is broad and flat-topped with steep and symmetrical slopes, and pitted with numerous small kettles. It extends westward three fourths of a mile and then, bending sharply to the west of south, is prolonged an equal distance in that direction to the northwest corner of High Lake. The southern half of this portion, however, is composed of gravel; the transition from till to gravel being abrupt and marked only by a slight change in the trend. The gap between the ends of the two gravel ridges above described is almost closed by a series of broken ridges of sand, generally less than ten feet high, but rising in one sharp peak to forty feet.

From the central mass of the till-ridge two short spurs project toward the south. One of these is separated by only a small gap from a ridge of sand which continues in the same direction to the northeast corner of High Lake and along its eastern border. On the north it is broad, rounded, and 40 feet high, but narrows and falls toward the south to a height of 5 feet, then widens and rises to 35 feet at the southern end. The lowest part of this ridge is a pile of angular bowlders up to a foot in diameter, with the interstices filled with sand.

The till-ridge is prolonged a mile or more to the northeast by a broad elevation of complex structure and topography. The greater portion of its mass seems to be composed of sand, which forms the highest peaks, 65 and 70 feet above lake level. An

area of at least twenty-five acres is studded with mounds and kettles, averaging about one each to the acre. One of these mounds has been excavated, and is shown to be made up of a uniform mixture of two thirds coarse gravel and one third clay. The clay forms a tough cement which holds up the material in a perpendicular face. The mixture might be called a clay conglomerate. A few large boulders occur in this tract. It is continued on the east by an isolated gravel mound rising to 65 feet above lake level.

The system of ridges forms an irregular parallelogram which nearly encloses the basin of High Lake. The northern part of the basin is occupied by a tamarack swamp. The area of open water is about half a square mile, mostly from 10 to 35 feet deep. It is deepest toward the south and west shores. There are no inlets except ditches from a few insignificant marshes, and in summer evaporation equals or exceeds supply. The overflow is by a small ditch to Bear Lake. The basins of the two lakes are really continuous, being only partially separated by the sand and boulder ridge. That their waters were once united is shown by a well-developed beach which borders the ridge and fills the gap between it and the till-spur.

This peculiar grouping of diverse and strongly marked features forms a puzzle difficult of solution. The east-west gravel ridge presents the characters of a subglacial esker, yet its height, steepness of slope, short extent and isolation are unusal. The presence of the great kettle hole piercing its center from top to bottom is not the least remarkable feature and contributes to the general impression of unnaturalness. The north-south ridges are sufficiently esker-like, but the western one is continuous, without notable change in form or direction, with the till ridge. The latter is an esker in form but its material is that of a submarginal moraine. Its northeastward extension presents some of the characters of a pitted sand plain or esker-delta, but it is complicated by the presence of the clay conglomerate and the kame-like sand and gravel knobs. The general indications of the surrounding country are that the Saginaw ice here moved

to the east, southeast and south, but it seems impossible to interpret the local phenomena upon that supposition. If the till ridge is a frontal moraine the direction of ice movement was northward. During the formation of this moraine the ice was traversed by tunnels or cracks which surrounded a block occupying the High Lake basin. These openings formed to some extent the channels of glacial drainage, but the writer finds himself unable to conceive how any considerable quantity of the sand, gravel and boulders in the ridges could have been transported by running water and deposited in such irregular and disconnected heaps. The clearest mental picture he is able to construct is that of a high narrow crack or tunnel, perhaps gradually transformed by the collapse of its roof into an ice-walled canyon open to the sky. Into this crevasse the surface débris slid or was irregularly dumped until it was filled to a height considerably above the tops of the present ridges. The subsequent removal of the walls permitted the pile to spread and assume such form as gravity and the coherence of the material permitted. In form the main gravel ridge is much like the pile of iron ore seen in the yard of a modern blast furnace and perhaps it may be regarded as a dump moraine formed under peculiar conditions. At the position of the large kettle the crack must have divided around an isolated ice-block or island which, although not more than two hundred yards in diameter, persisted through the whole period of filling, the bulk of the material being deposited equally on each side of it. Genetic classification of the system as a whole seems impossible. It might be called an esker-kame-moraine.

About five miles west of High Lake, along the valley of Turkey Creek lies the system of eskers shown in Fig. 2. The valley is here from one fourth to one half a mile wide and bounded by well defined bluffs. The valley floor is occupied for several miles by a peat bog containing a dozen small lakes. About one mile of it is traversed by a series of sand ridges and mounds disposed in characteristic eskerine patterns and contours. The direction of drainage was plainly northward. The main ridge

is 200 to 300 feet wide and fifteen to twenty feet high with a rather flat crest rising in occasional knolls to twenty-five and thirty feet. The northern portion of the series consists of a group of irregular islands and mounds of considerable mass which is perhaps the representative of an esker-delta. No excavations or cuts have been made and the surface shows no material but sand with an occasional small boulder. The arrangement of the ridges and mounds is such as to enclose between them and the bluff the basin of Gordy's Lake of about fifty acres extent and thirty-five feet in depth. High and Gordy's lakes owe their existence and outline to the presence of eskers and they seem worthy to constitute a distinct species of glacial lakes to be known as esker lakes.

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CORRELATION OF THE KINDERHOOK FORMATIONS OF SOUTHWESTERN MISSOURI.

In a recent geological report on Greene county, Missouri,[1] by Professor Edward M. Shepard, the stratigraphy of a portion of the southwestern part of the state surrounding the city of Springfield, has been described in detail. Some of the correlations proposed for the Kinderhook formations, however, are erroneous because of the almost entire disregard of paleontological evidence. The Kinderhook formations in the area are not abundantly fossiliferous, and unless careful search be made for fossils they may be easily overlooked. All the principal formations, however, contain distinctive faunas which furnish the data for a definite correlation of the beds.

The formations described by Shepard that must be included in the Kinderhook, are as follows, beginning with the lowermost, the names being those used in the report:

1.	Eureka or black shale	0 to 4 feet
2.	King limestone	1 to 15 feet
3.	Sac limestone	1 to 18 feet
4.	Phelps sandstone	0 to 4 feet
5.	Louisiana limestone	0 to 8 feet
6.	Hannibal sandstone and shale	10 to 90 feet
7.	Chouteau limestone	3 to 30 feet

The most conspicuous of these formations in the region covered by the report are the Sac limestone, the so-called Hannibal sandstone and shale and the so-called Chouteau limestone. In his geological map Shepard has recognized only three divisions in the series which correspond in general with the three formations just named. The Eureka shale and the Phelps sandstone are also formations which are apparently worthy of separate definition, but the King limestone and the so-called Louisiana limestone may prove, upon sufficient investigation, to be nothing but

[1] A Report on Greene county, by EDWARD M. SHEPARD, Geol. Survey of Missouri, Vol. XII, pp. 12–245 (December 1898).

lithologic facies of the Sac limestone. The strict correlation of the formations called Louisiana limestone, Hannibal sandstone and shale, and Chouteau limestone with the formations recognized under these names in the central and northeastern portion of the state cannot be sustained, as will be shown in the following pages, and in the present paper the names Northview sandstone and shale and Pierson limestone will be substituted for Hannibal sandstone and shale and Chouteau limestone.

The four lowermost of the formations in the preceding list, were referred by Shepard to the Devonian, but in view of the well defined Kinderhook faunas that are present in the Eureka shale and the Sac limestone, such a correlation cannot be sustained.

Eureka shale.—This formation has been recognized by Shepard in but few localities in the area covered by his map, and is restricted, for the most part, to the southwestern portion of the region where it attains its maximum thickness. Outside of this portion of the area, a few inches of shale have been recognized at several localities lying above the magnesian limestones, which are referred to this formation. Near Frazer's, at the chief locality for the Eureka shale cited by Shepard, the following fossils were collected by the writer:

1. *Lingula* sp. cf. L. *subspatulata* M. & W.
2. *Orbiculoidea* sp. undet.
3. *Chonetes* sp. cf. *C. logani* N. & P. or *C. ornatus* Shum.
4. *Ambocoelia parva* Weller.
5. Phyllocarid crustacean.
6. Fish scales?

The most common fossils in the fauna are the Lingulas, in this respect simulating the Eureka shale fauna of northern Arkansas which has been described by Williams.[1] *Orbiculoidea* is not recorded from Arkansas by Williams, although there is no reason why the genus should not be present in the Eureka shale of that state. The *Chonetes* found at Frazer's is evidently identical with one of the species of this genus recorded by Williams,

[1] Am. Jour. Sci. (4), Vol. VIII, pp. 139–152.

and is probably identical with one of the common Chouteau species of the genus. *Ambocoelia parva* was first described from the Northview sandstone, and the specimens from the shale seem to be indistinguishable from the types of the species except that they are more or less crushed. No crustaceans are recorded by Williams, but Phyllocarid crustaceans similar to those noticed in the fauna are not of uncommon occurrence in similar shale formations. Fish remains were detected by Williams in the Arkansas beds. No specimens of the *Leiorhynchus subspatula* noticed by Shepard[1] from this locality were detected by the writer.

Notwithstanding the presence of some forms in this fauna at Frazer's which have not yet been recognized in the Eureka shale of Arkansas, and the absence of others which are known to occur there, when we consider the poorly preserved nature of the fossils in all the localities and the stratigraphic relations of the beds containing them, the similarity between the faunas of the two regions is sufficient to establish the correlation, in a general way, of the beds containing them.

In regard to the age of the Eureka shale fauna in Arkansas Williams[2] says:

> The fauna of these fine shales in Arkansas, terminating and following the black shales, is unmistakably much higher than the Genesee black shale of New York. Faunally it is the correlative of the Louisiana or lithographic limestone, and is thus as late as the Kinderhook stage of the Eocarboniferous.

The beds indicated in the quotation are the fine green shales which always follow without any break in the sedimentation, the typical black Eureka shale when the two members are both present. Usually the black shales, in Arkansas, contain almost no fossils save *Lingulus*, but at one locality on War Eagle Creek a fauna from the black shales is noted which does not differ essentially from that in the greener beds.

Recent careful studies among the Kinderhook faunas of the Mississippi valley have given a basis for a more definite

[1] Loc. cit., p. 67. [2] Loc. cit., p. 149.

correlation of the Eureka shale fauna than Williams was able to make.[1] As will be shown, the fauna may be correlated definitely with that of the upper Kinderhook, that portion of the series which lies above the Chonopectus sandstone in the Burlington section.

The specimens referred to *Cyrtina acutirostris* by Williams are probably not representatives of the typical form of this species, but of a variation which may prove to be an undescribed form which is present in the Sac limestone and in the typical Chouteau limestone. *Spirifer marionensis* is a common species in the upper Kinderhook. The species recorded as *S. ? compactus* Meek is certainly *S. peculiaris* Shum., a common and variable species in the upper Kinderhook which possibly runs up into the lower portion of the Burlington limestone. *Athyris hannibalensis* is only a small form of *A. lamellosa*, and the two are not specifically distinct. It is common in the upper Kinderhook of southwestern and southeastern Missouri, but has not been recognized in the Burlington section. The three forms of *Chonetes* recorded by Williams are probably all present in the upper Kinderhook. The species of *Productus* referred to *P. hallanus* Walc. is not that species, but the specimens so identified are identical with a common species in the Sac limestone which has also been recognized in the typical Chouteau of central Missouri and in the upper beds of the Kinderhook in southeastern Missouri. The pedicle valve resembles *P. hallanus*, but the brachial valve does not have the concentric markings of that species. The orthids recorded by William are like those in the upper Kinderhook faunas elsewhere. *Leptaena rhomboidalis* is present in almost every upper Kinderhook fauna but has not been recognized in the Chonopectus fauna, nor in that of the Louisiana limestone. The additional species recorded by Williams afford little evidence as to the age of the fauna.

[1] Many of the Arkansas collections studied by Williams were made by the writer as an assistant to Professor Williams under the auspices of the United States Geological Survey. These collections were also carefully studied by the writer in Professor Williams' laboratory during the winter of 1894–5.

The paleontological evidence, as shown above, points conclusively to the Kinderhook age of the Eureka shale of Arkansas, and not merely may the fauna be correlated with the Kinderhook in general, but with that portion of the Kinderhook which is represented by the Chouteau limestone of central Missouri. The fauna is younger than the Chonopectus fauna of the Burlington section, and is also younger than the fauna of the Louisiana limestone if the generally accepted view as to the stratigraphic position of this formation, at the extreme base of the Kinderhook, be the correct one.

The Eureka shale in Missouri, as described by Shepard, is doubtless a stratigraphic continuation of the Arkansas formation, though the actual time of its deposition may have been a little earlier. The Kinderhook sea, in southwestern Missouri and northern Arkansas, is believed to have been transgressing upon the land to the southward. The Eureka shale facies of sedimentation is believed to have been a transgressing formation associated with the trangression of the sea to the southward, it being the initial sedimentation upon the newly submerged land surface. This formation, therefore, in the region covered by the Greene county report, was probably deposited a little earlier in time than its stratigraphic equivalent in northern Arkansas, as it is followed by the Sac, Northview, and Pierson formations. In northern Arkansas this same stratigraphic unit represents the final stages of the Kinderhook, it being immediately followed by the St. Joe marble whose fauna indicates the Burlington age of the formation. The black Eureka shale in Arkansas, with its associated greenish shale beds and the equivalent Sylamore sandstone, may be considered as the sole representatives of the Kinderhook in that state, the time of their deposition being the final stages of the Kinderhook epoch.

Sac limestone.—The King limestone, described by Shepard, has not been studied by the writer. It is said to be[1] "rarely over a foot or two in thickness except outside and south of the area." A further statement is made in regard to the formation[2]

[1] Loc. cit., p. 71. [2] Loc. cit., p. 72.

to the effect that "to the south . . . . it underlies, directly, the Phelps sandstone, the Sac limestone being absent." This manner of occurrence would seem to indicate that the formation was but a facies of the Sac limestone, it being thin or almost absent where the typical facies of that formation is well developed, becoming thicker and replacing the lithologic facies described as the Sac limestone, to the south. A careful search for fossils should be made in the limestone in order to determine whether or not its fauna is the same as that in the Sac limestone.

The typical facies of the Sac limestone is well exposed in numerous outcrops along the Sac River and its branches in the northern portion of Greene county, the name of the formation being selected by Shepard[1] because of this occurrence. It is a hard, bluish gray, compact limestone with a maximum thickness of eighteen feet, usually deposited in beds of from six to ten inches thick with thin greenish shaley partings between the beds. The rock has been quarried somewhat extensively at several points and shipped to Springfield to be used as curbing. Shepard referred the formation with those beneath it, to the Devonian, considering it to be of Hamilton age. No fossils were secured by him in the formation itself by means of which such a correlation could be established, but in the overlying Phelps sandstone, numerous waterworn fragments of fish-teeth were secured, some of which were identified as *Ptyctodus calceolus*. This genus of fishes is usually considered to be limited to the Devonian, and its presence in beds overlying the Sac limestone was considered to be sufficient evidence to justify the reference of the underlying beds to the Devonian. A study of the invertebrate fauna of the Sac limestone, however, serves to definitely correlate the formation with the lower portion of the Chouteau limestone of central Missouri, and leads to the conclusion that either the waterworn fragments of fish-teeth have been wrongly identified, or that the genus *Ptyctodus* has a higher geological range than has hitherto been supposed.

Although no fossil fauna was secured from this formation

[1] Loc. cit., p. 74.

by Shepard, the Sac limestone is really fossiliferous in most localities where it is exposed, and frequently affords beautifully preserved specimens. One of the best fossil localities in the formation known to the writer, is at an old quarry about eight miles northeast of Springfield, east of the Fair Grove road where it crosses the north branch of the Little Sac. The species collected at this locality will be enumerated, with notes on their occurrence elsewhere.

1. *Platycrinus ollicula* S. A. M.
2. *Platycrinus annosus* S. A. M.
3. *Platycrinus absentivus* S. A. M.

   All three of these species of Platycrinus were originally described from the Chouteau limestone of Pettis county, Missouri.
4. *Dichocrinus* sp. undet. A single specimen of this crinoid has been observed. It is too imperfect for specific identification, but it resembles *D. inornatus* from the upper Kinderhook beds at Le Grand, Iowa.
5. *Schizoblastus roemeri* Shum. This species originally described from the Chouteau limestone at Providence, Missouri, is one of the commonest species in the Sac limestone at the locality under discussion.
6. *Leptaena rhomboidalis* Wilck. This species is entirely absent from the lower Kinderhook beds at Burlington, Iowa, making its first appearance in the upper "Yellow Sandstone," bed No. 5.[1] The species is also absent from the Louisiana limestone fauna of the lower Kinderhook, but is universally present in the upper Kinderhook.
7. *Chonetes logani* N. & P. This little species is particularly characteristic of the oolite bed No. 6[2] of the Burlington section. It is also possible that *C. ornatus* Shum., from the typical Chouteau limestone, is not specifically distinct.
8. *Productus blairi* S. A. M. This species was originally described from the Chouteau limestone of Pettis county, Missouri.
9. *Productella concentrica* H. This species occurs abundantly in the Chouteau limestone of central Missouri, and is also a member of the oolitic limestone (bed No. 6) fauna at Burlington, Iowa.
10. *Schizophoria swallovi* H. The specimens referred to this species are smaller than the normal form of the species in the Burlington limestone. Specimens agreeing in all respects with those from the Sac limestone, are also present in the typical Chouteau limestone.

[1] Iowa Geol. Survey, Vol. X, p. 76. [2] Loc. cit., p. 77.

11. *Rhipidomella burlingtonensis* H. A small form of this species is present in the fauna, which agrees in all respects with specimens from the Chouteau limestone.
12. *Pugnax missouriensis* Shum. The Sac limestone specimens of this species are indistinguishable from specimens of the same species from the Chouteau limestone at Chouteau Springs, Missouri.
13. *Athyris prouti* Swall. This species has not been seen from the Chouteau limestone of central Missouri, but is a common species in the upper portion of the Kinderhook near Sulphur Springs, Missouri.
14. *Athyris* sp. undet. A small species somewhat resembling the Devonian *A. fultonensis* occurs in the Sac limestone fauna, and the same form is present in the Chouteau limestone at Providence, Missouri.
15. *Cleiothyris* sp. undet. Specimens of a small lenticular species resembling *C. hirsuta* are present in the fauna, and the same species occurs in the Chouteau limestone at Providence, Missouri.
16. *Spirifer peculiaris* Shum. This is one of the commonest species of the Sac limestone fauna, as it is also of the Chouteau limestone of central Missouri. The same or a closely allied species occurs in bed No. 5 at Burlington.
17. *Spirifer latior* Swall.? This species was originally described from the Chouteau limestone of Cooper county, Missouri, but no illustrations of it have ever been published. The Sac limestone specimens are identified thus with some doubt, but in any event a species identical with them occurs in the Chouteau limestone of Pettis county.
18. *Spirifer striatiformis* Meek? This identification is only provisional, but specimens of the same species occur in the Chouteau limestone in Pettis county.
19. *Syringothyris missouri* H. & C. This species is only known elsewhere from the Chouteau limestone at Chouteau Springs, Missouri.
20. *Cyrtina* sp. undet. The same species has been recognized from the typical Chouteau limestone.
21. *Dielasma* sp. undet. A rather large, smooth species of this genus is present in the fauna, which is apparently identical with specimens from the Chouteau limestone of Pettis connty.
22. *Capulus* sp. undet. Several forms of this genus are present in the fauna which may belong to several distinct species.
23. Corals and Bryozoa. Several undetermined species of corals and bryozoa of little diagnostic value, occur in the fauna.
24. Fish teeth. Fragments of fish teeth are not uncommon in the fauna.

From the list of fossils just given it will be seen that the fauna of the Sac limestone corresponds closely with that of the typical Chouteau limestone of central Missouri, and more especially with the lower division of the Chouteau limestone as described by Swallow.[1] There is no foundation whatever for correlating it with the Hamilton formation of the Devonian, but several of the species are also present in beds 5 and 6 of the Kinderhook at Burlington, Iowa.

The formation referred by Shepard to the Louisiana limestone, is described as follows by that author:[2]

> The lowest member of the Carboniferous is not so variable in composition and texture as the other two. It frequently, however, possesses such lithologic characters as to make it difficult to distinguish it from the associated Devonian rocks. As only a few obscure fossils have been found in this region, its identification is dependent entirely upon position and lithologic characters.

The Devonian formation referred to in the above quotation is the Sac limestone. The difficulty in separating the so-called Louisiana limestone from the Sac limestone is frequently indicated by Shepard by such statements as the following:

> P. 85: . . . . an outcropping of what seems to be some eight or ten feet of Louisiana, though it may prove to be a somewhat modified form of Sac limestone; p. 76: it is barely possible that this particular rock may be Louisiana, and not the Sac limestone; p. 77: there is frequent difficulty, on account of lithologic characters, in separating it [the Sac limestone] from the Louisiana when the Phelps sandstone is absent; p. 77: it is a noticeable fact that, when the Devonian [the Sac limestone] is present, the Louisiana limestone is usually, though not always, absent.

Among the localities mentioned for the Louisiana limestone, the best exposure where both this formation and the Sac limestone are present, is said to be at the Newton mound,[3] and the description of its stratigraphic position at this locality is as follows: "Immediately underlying the Hannibal shales and overlying the Phelps sandstone, are ten feet of this limestone." The Phelps sandstone at this same locality is described in another

[1] Geol. Surv. Mo., Rep. I and II (1855), p. 102.

[2] Loc. cit., p. 84. [3] Loc. cit., p. 84.

place[1] as follows: "a number of fragments of the typical sandstone with fish teeth were found on the slope. A hurried search did not discover this sandstone uncovered." If this last statement be correct, it is difficult to see how the fact stated in the first of the above quotations can be demonstrated. Another locality mentioned where the Louisiana limestone is said to be "associated with the Devonian" is on the Cochran farm. The so-called Devonian described at this locality is the Sac limestone and "loose fragments" of Phelps sandstone in which "no fish teeth were found." In neither of these localities is it demonstrated that the so-called Louisiana limestone and the Sac limestone are distinct formations separated by the Phelps sandstone. The loose fragments supposed to belong to this sandstone can be of no value in elucidating the stratigraphy. In none of the other localities given for the Louisiana limestone is there any evidence given to show that the formation is distinct from the Sac limestone, and the careful reader of the Greene county report is forced to the conclusion that its author mistook mere lithologic variations of a single stratigraphic unit as two distinct formations. A careful search for fossils, however, should be made in the outcrops of so-called Louisiana limestone, for the purpose of demonstrating its identity with the Sac limestone.

Phelps sandstone.—This formation has been examined by the writer only at its typical locality in the neighborhood of the Phelps mines. It has been recognized by Shepard, however, as a more or less continuous formation throughout the area covered by his report, and is frequently characterized by the waterworn fragments of fish teeth. At the Phelps mines these teeth are somewhat abundant, but are so waterworn that in every specimen observed the original form has been destroyed. Some of these specimens have been identified by Shepard as *Ptyctodus calceolus*, and it was chiefly from the evidence of this identification, with no knowledge of the invertebrate fauna of the Sac limestone, that the Phelps sandstone was referred to the Devonian, such a reference carrying with it, of necessity, all the

[1] Loc. cit., p. 81.

underlying beds down to and including the Eureka shale. This sandstone resembles, lithologically, the Sylamore sandstone of Arkansas; both formations carry fish remains and also numerous black phosphatic nodules.

Northview sandstone and shale. — In the older geological reports these beds have been known as the Vermicular sandstone and shales from the abundance of worm burrows which occur in the sandstones. Shepard[1] has considered these beds to be the equivalent of the Hannibal shales of the Mississippi River section which are supposed to lie beneath the Chouteau limestone, and he has so designated them in his report. These beds in southwestern Missouri, however, are certainly not the equivalent of the typical Hannibal shales, if the relationship of that formation to the remainder of the Kinderhook series be properly understood, and as they possess a characteristic individuality of their own throughout a considerable geographic area, it seems advisable to designate the formation by a special name. The sandstones of the formation are abundantly fossiliferous near Northview, in the western edge of Webster county, and therefore this name is suggested for the formation.

Shepard's investigations have shown that the formation has a thickness ranging from ten to ninety feet. It is typically made up of two members, a lower bluish shale and an upper fine-grained yellowish sandstone. The two members of the formation grade from one into the other with no sharp line of separation, and one member is frequently thickened at the expense of the other, the lower shale member being the most peristent.

The fauna of this sandstone at Northview has been described in detail in another place,[2] and contains the following species.

1. *Zaphrentis* sp. undet. A few fragments of specimens of this genus have been observed.
2. *Scalarituba missouriensis* Weller. This is the name which has been applied to the worm borings which penetrate the sandstone in all directions.

[1] Loc. cit., p. 86.

[2] Kinderhook Faunal Studies. I. Fauna of the Vermicular Sandstone at Northview, Webster county, Missouri. Trans. St. Louis Acad. Sci., Vol. IX, pp. 9–51.

3. *Orthothetes inaequalis* Hall? In the paper cited above, this shell was identified as *O. chemungensis*. It is probably identical with one of the species in the upper Kinderhook beds at Burlington, but may not be the *O. inaequalis*.
4. *Schizophoria swallovi* Hall. The specimens of this species resemble those from the subjacent Sac limestone, and also those from the superjacent Pierson limestone, but are usually larger than the Sac limestone specimens.
5. *Rhipidomella burlingtonensis* Hall. The specimens of this species are not unlike those from the other Kinderhook formations of the region, but are usually larger than the Sac limestone specimens.
6. *Chonetes illinoisensis* Worthen? The specimens so identified should perhaps rather be referred to *C. multicosta* Win., described from the "yellow sandstone" at Burlington, Iowa.
7. *Productella concentrica* Hall. A single individual of this species resembles specimens of the same species from Burlington, Iowa.
8. *Spirifer marionensis* Shum. This is one of the most abundant species in the fauna of the Louisiana limestone at its typical exposures. It is also a common species in the oolite bed at Burlington and occurs in the subjacent "yellow sandstone" at the same place, as well as being more or less common in most of the upper Kinderhook faunas.
9. *Spirifer striatiformis* Meek? This species is probably identical with the one so identified from the Sac limestone.
10. *Syringothyris carteri* Hall. Several specimens from Northview have been referred to this species, although the characteristic syrinx and punctate shell structure of the genus have not been observed.
11. *Ambocoelia parva* Weller. This species has only been observed in this fauna and in the Eureka shale.
12. *Athyris lamellosa* Lev. This species is a common one in the superjacent Pierson limestone, and is also a member of the typical Chouteau limestone fauna.
13. *Cleiothyris* sp. undet. These specimens are possibly identical with those in the Sac limestone.
14. *Dielasma* sp. undet. This shell is perhaps the same as that described by Winchell as *Centronella allei* from the upper "yellow sandstone" at Burlington.
15. *Crenipecten winchelli* Meek? This is a species which was originally described from the Waverly sandstones of Ohio.
16. *Crenipecten laevis* Weller. This species was described from Northview, and is not known elsewhere.

17. *Pernopecten cooperensis* Shum. This is one of the commonest species in the Northview sandstone, and is also one of the most characteristic species of beds 5 and 6 of the Burlington section. It was originally described from the Chouteau limestone of Cooper county, Missouri, and is a common shell in some beds of the Chouteau limestone.
18. *Modimorpha northviewensis* Weller. This species has only been recognized at Northview.
19. *Macroden* sp. undet. This species has not been identified, but the genus is represented in the upper "yellow sandstone" fauna at Burlington by a very common species. The genus is also represented in the typical Chouteau limestone.
20. *Cardiopis radiata* M. and W. This species originally described from the goniatite limestone at Rockford, Indiana, also occurs in the Chouteau limestone in Pettis county, Missouri.
21. *Cardiopsis erectus* Weller. This species was first described from Northview, and has not been recognized elsewhere.
22. *Palaeoneilo* sp. undet. This species was formerly identified with a query as *P. constricta* Con., but it is probably distinct. It is closely allied to *P. microdonta* Win. of the upper "yellow sandstone" at Burlington, but is usually larger.
23. *Palaeoneilo truncata* H. This species, originally described from the Waverly sandstones of Ohio, is represented in the upper "yellow sandstone" at Burlington by *P. barrisi* W. & W. a similar but smaller species. The genus *Palaeoneilo* does not occur in the Chonopectus fauna at Burlington, and has not been recognized in any of the lower Kinderhook faunas.
24. *Schizodus aequalis* Hall. This is a Waverly sandstone species, and has not been recognized elsewhere in the Kinderhook.
25. *Elymella missouriensis* M. & G. This species was originally described from the Chouteau limestone of Pettis county, Missouri.
26. *Promacrus websterensis* Weller. This was described as a new species from Northview.
27. *Promacrus cuneatus* Hall. In the description of the fauna of the Chonopectus sandstone,[1] this species was provisionally included. Since that time, however, through the courtesy of Dr. E. O. Hovey, of the American Museum of Natural History, the type specimen of *P. cuneatus* has been examined by the writer, and it proves to have come from the upper "yellow sandstone," bed No. 5, at Burlington. The genus *Promacrus* is represented by several species in the

[1] Kinderhook Fauna Studies. II. Fauna of the Chonopectus Sandstone at Burlington, Iowa. Trans. St. Louis Acad. Sci., Vol. X, pp. 57–129.

typical Chouteau limestones of central Missouri. It is not known anywhere in the lower Kinderhook beds, and is probably a characteristic form of the upper Kinderhook faunas.

28. *Sanguinolites websterensis* Weller. This species was described as new from Northview, but probably occurs also in the Waverly sandstones of Ohio.
29. *Edmondia* sp. undet. This species was originally identified as *E. burlingtonensis* W. & W., but an examination of the types of that species from the Chonopectus sandstone have led to the conclusion that the two shells are not specifically identical.
30. *Edmondia missouriensis* Weller. This species was described as new from Northview.
31. *Tropidodiscus cyrtolites* Hall. This species, originally described from the goniatite limestone at Rockford, Indiana, is also recorded from the Waverly sandstones of Ohio.
32. *Euphemus?* sp. undet.
33. *Bucania?* sp. undet.
34. *Bellerophon* sp. undet.
35. *Mourlonia northviewensis* Weller. This was described as a new species from Northview.
36. *Pleurotomaria* sp. undet.
37. *Platyschisma missouriensis* Weller. This was described as a new species from Northview.
38. *Straparollus* sp. undet.
39. *Phanerotinus paradoxus* Winch. This species, first described from Burlington, is probably a member of the upper "yellow sandstone" fauna at that locality.
40. *Capulus* sp. undet.
41. *Porcellia rectinoda* Win. (?) The correct horizon of the original types of this species at Burlington is not known. Two other members of the genus, however, occur in the Chonopectus sandstone. The genus is also known to occur higher up in the Burlington limestone.
42. *Loxonema* sp. undet. This species is of the general form of specimens which are not uncommon in the Chouteau limestone in Central Missouri.
43. *Orthoceras indianense* Hall. These specimens, formerly identified as *O. Chemmigense* Swall., are probably identical with a form common in the oolitic limestone (bed No. 6) at Burlington, which may probably be identified with *O. indianense* of the goniatite limestone at Rockford, Indiana.
44. *Triboloceras digonum* M. & W. This species is a common one in some portions of the Chouteau limestone of central Missouri.

45. *Proetus* sp. undet.
46. *Spirophyton* sp. undet. These fucoid markings are abundant everywhere in the sandstone, and with the worm borings are the only fossils which are always recognizable in this formation.

When the description of the Northview fauna was published no differentiation of the faunas of the "yellow sandstone" at Burlington was possible. Since that time, however, a study of the type collections from that locality has shown that two quite distinct yellow sandstone faunas occur.[1] The lower is characterized by *Chonopectus fischeri* N. & P., and the bed containing it, bed No. 2, has been called the Chonopectus sandstone. The upper yellow sandstone is characterized by the presence of *Pernopecten*, *Promacrus*, and *Palaeoneilo*, genera which are wanting from the Chonopectus fauna. These same genera, however, are among the most characteristic forms of the Northview sandstone, and all of them are also present in the fauna of the typical Chouteau limestone of central Missouri. The faunas of the Northview sandstone and of the upper yellow sandstone at Burlington may be considered as analagous, and they may without hesitation be considered as one facies of the upper Kinderhook or Chouteau fauna.

The Northview shales are usually quite barren of fossils, but at a few localities they are abundant. They are mostly brachiopods and corals, but no complete list of species can be given in this place. The collections in Walker Museum contain only a few specimens from this bed near Bolivar in Polk county, the species represented being *Athyris lamellosa*, *Reticularia cooperensis*, and *Rhipidomella burlingtonensis*. These species are all present in the fauna of the typical Chouteau limestone elsewhere.

Pierson limestone.—This is a fine-grained, buff colored, gritty limestone having a maximum thickness, according to Shepard,[2] of thirty feet, being the formation designated by him as the Chouteau limestone. In view of what has already been written in regard to the faunas of the Sac limestone and the Northview sandstone, it will be recognized that the formation is by no

[1] Iowa Geol. Surv., Vol. X, p. 79. [2] Loc. cit., p. 83.

means an exact equivalent of the Chouteau limestone of central Missouri, but represents merely the upper portion of that formation. The formation is well exposed along Pierson Creek near the zinc mines, and since it possesses an individuality of its own as a formation, over a rather extensive area, it may be designated as the Pierson limestone. The formation is frequently non-fossiliferous, but fossils often occur and are usually well preserved. One of the best fossil localities is on the south branch of the Little Sac Creek, about two miles north of Lyman station on the St. Louis and San Francisco railroad. At this locality the following fauna was collected which may be taken as a typical representation of the fauna of the whole formation.

1. *Zaphrentis* sp. undet. A single imperfect specimen of this genus is the only coral of the fauna.
2. *Leptaena rhomboidalis* Wilck. This species is of frequent occurrence in the fauna.
3. *Orthothetes* cf. *O. inflatus* W. & W. A species similar to *O. inflatus*, but much flatter, is rather common in the fauna. The same shell is associated with *O. inflatus* in oolitic bed No. 6 of the Burlington section.
4. *Chonetes* sp. undet. A large species frequently having a width of more than twenty mm is not uncommon in the fauna. It resembles *C. illinoisensis* Worthern, but is much larger and should perhaps be identified as *C. shumardianus* DeKon.
5. *Chonetes logani* N. & P. ? A species having the general form of *C. Logani* is not uncommon in the fauna, but the preservation is not such as to exhibit the characteristic surface markings of that species.
6. *Productus arcuatus* Hall. This species is particularly abundant in the oolite bed at Burlington, and the Pierson limestone specimens are of the typical form.
7. *Productus burlingtonensis* Hall. Specimens of this species indistinguishable from those in Burlington limestone, occur in the Pierson limestone.
8. *Productus laevicostus* White. This species makes its first appearance in the Chonopectus sandstone of the Burlington section, and ranges up into the base of the Burlington limestone.
9. *Productus punctatus* Martin. Specimens of this species are not uncommon in the Pierson limestone. In the Burlington section it makes its first appearance in bed No. 7, the topmost bed of the Kinderhook at that locality.

10. *Schizophoria swallovi* Hall. Specimens of this species identical with those in the Burlington limestone are present in this fauna.
11. *Rhipidomella burlingtonensis* Hall. Individuals of this species from the Pierson limestone resemble those from the Northview sandstone, and are more nearly like typical representatives of the species from the Burlington limestone than are the Sac limestone specimens.
12. *Camarophoria* sp. undet. This species is of the general form of *C. caput-testudinis* White, the types of which are from the base of the Burlington limestone, and bed No 7 of the Kinderhook at Burlington. The Pierson limestone species, however, differs from *C. caput-testudinis* in being a much smaller and flatter shell.
13. *Rhynchonella cooperensis* Shum. This species was originally described from the Chouteau limestone of Cooper county, Missouri.
14. *Athyris lamellosa* Lev. This is one of the commonest species of the fauna, and specimens from the Pierson limestone are indistinguishable from those in the Burlington limestone.
15. *Spirifer marionensis* Shum. This is the same species that occurs in the Northview sandstone. It is one of the commonest members of the Pierson limestone fauna and also of the oolitic limestone fauna at Burlington.
16. *Spirifer latior* Swall.? The specimens identified as this species are not different from those in the fauna of the Sac limestone.
17. *Spirifer peculiaris* Shum. The Pierson limestone representatives of this species are not unlike those from the Sac limestone.
18. *Spirifer grimesi* Hall. This Burlington limestone species is represented by typical individuals in the Pierson limestone.
19. *Spirifer* sp. undet. This species has the high area of Syringothyris, but lacks the syrinx, and is apparently not punctate.
20. *Reticularia cooperensis* Swall. This species rarely occurs in the fauna. It is a common form in the typical Chouteau limestone and also occurs in the upper "yellow sandstone" at Burlington.
21. *Dielasma* sp. undet. These specimens have the general form and size of those recorded from the Sac limestone, but usually have more conspicuous lines of growth.
22. *Macrodon* sp. undet. A single imperfect specimen of this genus is the only pelecypod recognized in the fauna.
23. *Orthoceras* sp. undet. Fragmentary specimens of a species of Orthoceras are not uncommon in the fauna.

In the Pierson limestone fauna we find a disappearance of the pelecypod element which is so characteristic of the Northview sandstone, and a return of the brachiopods. Some of these

brachiopods are common to the Sac limestone, but there are introduced several species, such as *Spirifer grimesi*, *Productus burlingtonensis*, *Productus punctatus*, and *Athyris lamellosus* (which was also present in the Northview sandstone), which pass upward and connect the fauna with that of the Burlington limestone above.

Conclusions.—A critical examination of the Kinderhook faunas of southwestern Missouri, shows that the entire series of strata in that region referable to this division of the Mississipian series are to be correlated with the upper division of the Kinderhook, or the Chouteau limestone of central Missouri. This Chouteau fauna is not one uniform fauna throughout, but exhibits at least two rather well-defined facies, one brachiopod fancies generally characteristic of the limestones and another pelecypod facies characteristic of the more clastic sediments. In Greene county, Missouri, the brachiopod facies is present in the Sac limestone and the Pierson limestone, while the pelecypod facies is present in the Northview sandstone.

In the Burlington section, beds 5, 6, and 7 are apparently to be correlated with the Greene county formations, and in the faunas of these three beds the same brachiopod and pelecypod facies are exhibited, but in a different order, the pelecypod facies occupying bed 5, and the brachiopod facies beds 6 and 7.

In central Missouri, the region of the typical Chouteau limestone, opportunity has not been offered to study these faunas in situ. Among the material received from that region, however, the same two faunal facies may be recognized, though it is impossible to work out their interrelations without careful field investigation.

These two faunal facies apparently lived contemporaneously throughout the area covered by the upper Kinderhook sea, each one occupying those portions of the region where the local conditions were best adapted to its development, shifting about with local changes in the environment, and each one going on with its developmental changes with the progress of time. The faunas of the Northview sandstone and of bed No. 5 at Burlington,

have so much in common that they may be considered as representatives of a single fauna, yet they may not have been and probably were not strictly contemporaneous. They simply indicate that at some stage during the limited time period in which they both belong, there were present in each of these widely separated regions, conditions suitable for the existence of the same general assemblage of species.

The Chonopectus fauna, which underlies these faunas in the Burlington section, is not represented in southwestern Missouri; neither is the typical Louisiana limestone fauna present in the region.

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PROBLEM OF THE MONTICULIPOROIDEA. II

CRYPTOSTOMATA

CRYPTOSTOMATA are quite generally classed as Bryozoa, but their reference as such can still be treated as doubtful. They occupy, in fact, a central position in the disputed field of Paleozoic tabulate fossils. They are quite inseparable from Trepostomata which are most often classed as Cœlenterata. To prove them undoubtedly Bryozoa is to prove Trepostomata such also. To fail in that proof permits the latter to be classed as Tabulata, true Cœlenterata, and the Cryptostomata should then be carried with them.

Four similar groups of tabulate corals and bryozoons appear for their first geologic occurrence in the Ordovician (Lower Silurian). The Tabulata, or Alcyonarian corals, are there represented by a few but typical species, the Trepostomata are locally in great numbers, and with them are many Cryptostomata and a few Cyclostomata, the last being true Bryozoa. To the top of the Paleozoic these four groups remain associated, but there the Cryptostomata become extinct. Only in middle Mesozoic the fifth group, comprising the Chilostomata to which most living Bryozoa belong, appears at a time when even the Trepostomata have quite disappeared. The fifth and last group seems to come in suddenly, as did the others. Evidently the record is incomplete as to their origin, and the missing evidence has therefore to be supplied. Some Cryptostomata resemble in all ways the Trepostomata and these the Tabulata; others somewhat nearly simulate the Cyclostomata; and again it has been suggested[1] that they "are nothing more than Paleozoic Chilostomata," differing from these, however, in several ways. The problem centers about the Cryptostomata.

Besides this interest which the problem of phylogenic relationship affords to the paleontologist, the geologist finds, or can

[1] See EASTMAN, Text-book of Palæontology, p. 278.

find, most of them good zone markers. They are not especially difficult to recognize in the field, their more highly specialized shapes of frond and of cell pattern making them rather easier than Trepostomata in that respect. Their separation into species and arrangement in taxonomic divisions is facilitated by reliable macroscopic external characters as a rule. They afford also a great variety of neat cabinet specimens, and, in short, may be recommended as worthy of close acquaintance.

The student will find a ready knowledge of the Trepostomata a great aid to the understanding of Cryptostomata. In the former group one can select a simple supposed primitive skeletal structure, from which the others can be traced with increasing complexity or differentiation. The simplest Cryptostomata compare with the most complex Trepostomata, and, while serial arrangement of differentiated types can be made, the series appear not to begin within this group but in the Trepostomata. It is, therefore, further convenient to begin with species of this group which most resemble those of the other, avoiding also for the present the taxonomic definitions until after representative fossil species have been studied. The newest taxonomic arrangement[1] may conveniently be referred to, however, and this one divides the sub-order into eight families. They may well be arranged in three divisions or series:

Bifoliate	Cylindrical	Fenestrate
1. Ptilodictyonidæ	4. Arthrostylidæ	6. Fenestellidæ
2. Rhinidictyonidæ	5. Rhabdomesodontidæ	7. Acanthocladiidæ
3. Cystodictyonidæ		8. Phylloporinidæ

The relation of the three groups will be discussed later, but any one might be taken first, since they are coördinate, not successive, but related each to Trepostomata.

Our knowledge of the Cryptostomata may be considered fairly complete, although species and perhaps a family remain to be discovered, while others might be eliminated. This task of completing the knowledge of the several species and genera, their fixed and variable characters, is one worthy of attention

[1] EASTMAN, op. cit., p. 278.

from whoever may be in favorable position to obtain the fossils. For the present the best literature is not to be taken as alike reliable on all. In extreme cases a fortuitous or abnormal character in specimens of a species may have been mistaken as grounds for a new species, and this being then peculiar may be set up as a new genus, and in turn it affects the family. Owing to the more highly specialized structures as compared to Trepostomata, Cryptostomata are, as said, somewhat easier to learn, but they are more complex to study.

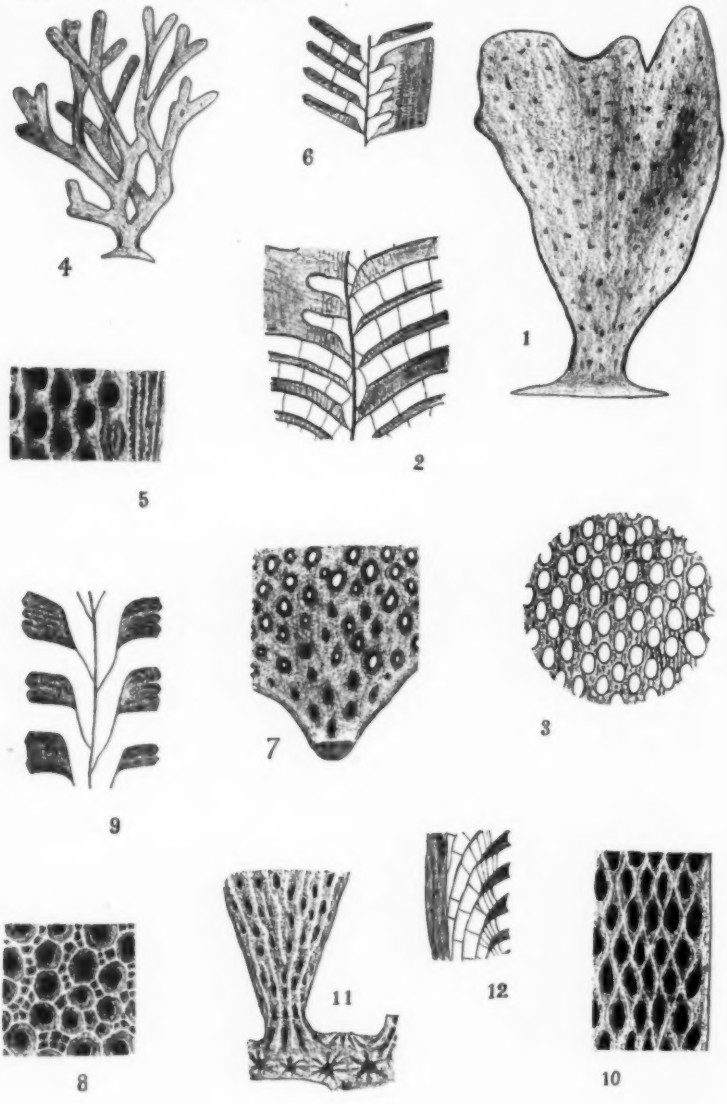
For the present purpose a few common, well-known species suffice. Taking the bifoliate group first:

Pachydictya foliata Ulr. (see Plate B, Figs. 1, 2, 3) is a leaf-shaped zoarium about 50^{mm} wide and 1 to 3^{mm} thick, with autocells 0.3 to 0.4^{mm} in diameter growing from a median plane and opening on either side, "bifoliate." It grows at the margin, the erect frond broadening as it increases in height. The growth is not quite uniform and a lobate, undulate shape prevails. The base or broad stem of the frond is therefore the more mature, thicker part, and there the cell increase ceases first and the margin changes to a solid, sharp, or rounded narrow border. Growing margins may also appear on the face of the frond, and when large, arising near the stem, produce a so-called trifoliate frond. A basal expansion incrusted the ground, and if this was broken off a new one developed from above the broken edge. Any injury destroying part of the frond surface gave rise to a similar growth.

The basal expansion grew perigene, the frond acrogene and so that the zoarial growth and cell increase is normally at the margins only. In the frond the cells arise on either side of a median plane, or so-called mesial plate or lamina, are directed at first vertically, but as younger cells arise between, above them, they turn laterally. Thus an immature or axial and a mature or peripheral region are distinguished. The mesial lamina is built as the extreme wall at the growing edge of the frond.

The cells at the beginning, *i. e.* at the mesial lamina, are thin walled, with mesopores at their angles, but later they are separated

JOUR. GEOL., Vol. IX, No. 2 Plate B



by mesopores, become oval and thick walled. They grow slowly in the peripheral region, to 1 or 1.5^{mm} in length with slightly increasing size. They have a few thin tabulæ, the first one in or near the axial part, the last one often at the aperture. The mesopores are small, numerous, closely tabulated, either distinct, or the tabulæ of neighboring mesopores overlapping in vesiculose way, or again in maturer stages they fill with granulose schlerenchyma. Mesopore walls are nearly always reduced so that those between mesopores are extant only vertically in zoarial direction, but mesopore corners and junction of mesopore walls to autocell wall are always partly developed. Mesopores are rarely distinct at the surface, and their space appears solid between autocells.

The arrangement of the cells is regular, alternating in vertical rows, and the surface pattern is easily used to distinguish the species. Maculæ or solid spots of filled mesopores and filled cells too, are regularly distributed over the surface and next to these the cells are a little larger sized. No cell increase is seen normally in the peripheral or mature region, not even in the maculæ.

The best specimens only show the peristome or circular wall margin papillose, and the interspaces or mesopore tabulæ granulose, or, when some walls are present, granostriate, as the maculæ and zoarial solid border usually are also. The preserved edge of a growing mesial (or median) lamina, I have not seen, but it was probably papillose. Corresponding to these structures, sections show so-called vertical or median tubuli in the midst of the double autocell wall, similar less distinct structures in the schlerenchyma of filled mesopores, and large ones in the mesial lamina. Warts and so-called tubuli on the interspaces sometimes represent reduced mesopore walls. Further details, dimensions, etc., characterizing the species may be passed over here.

One finds characters in *Pachydictya foliata* Ulr., such only as seen in Trepostomata also: bifoliate zoaria (*e. g.*, *Ceramophylla*), occur among them also: axial and peripheral region, autocells and vesiculose mesopores (*Prosopora*, *Fistulipora*), and maculæ

differ at most in degree of accentuation. The so-called vertical or median tubuli and the mesial tubuli differ most, but are comparable directly to acanthopores. Their numbers and small size here characterizes the species and genus, however, and unites to the Rhinidictyonidæ.

The question arises again as to what interpretation should be made of the zoarium. Apparently the same interpretation is necessary in *Pachydictya foliata* as in Trepostomata. E. O. Ulrich holds that the successive loculi between autocell tabulæ were each a zoœcium, and the autocell was built by successive generations of polypites and as to median and mesial tubuli, that they were a united system of canals. One may prefer the other interpretation for the following reasons. In any case the necessary interpretation is that the skeleton or zoarium was built by a cortex of zooids over its surface, since the mesopores are outside the cells or zoœcia, and must have been been built by super-zoarial secretion; and likewise the median tubuli which end not in the cells but above them. Admitting a cortex to have covered the zoarium, there is no explanation as to why successive generations instead of a single polypite should have built each cell, or how neighboring cells could have had, one four, the other three or five generations to build it. The so-called tubuli can be interpreted as the structural results of surface projections which they are really seen to be. One can explain the mesial lamina of the zoarium in this way, that, as compared to the palmate zoarium of certain Trepostomata, with long narrow axial surface and flat axial region, the bifoliate zoarium has a still more specialized, narrower axial region and the growth or axial edge being thus very narrow, the cortex bent rather than curved over it, the cell walls coinciding with the line of flexure coming to lie nearly in one plane, and to be more or less thickened. The mesial lamina is at the axial growth center, not as a germinal layer but a wall. The cell increase having ceased at full maturity at any part, the margin ceased to extend rapidly and a filled cell or "nonporiferous" margin formed.

Species of *Pachydictya*, *e. g.*, *P. acuta* Hall, might be described

intermediate to *P. foliata* and *Rhinidictya*, but one of this genus may suffice.

Rhinidictya mutabilis Ulr., is bifoliate, with autocells 0.2^{mm} or less in diameter (Plate B, Figs. 4, 5, and 6). It begins apparently as a small thin vertical blade 1 or 2^{mm} wide, with a small basal expansion. It grows in height rapidly, increasing more or less in apical width and branching to the length of 200^{mm} or less. As the zoarium enlarges, its basal expansion widens slowly, the cell apertures filling solid. The base or oldest part of the stalk becomes thick, more or less cylindrical, and solid surfaced. The zoarial branches thicken slowly, having ceased cell increase and built solid narrow margins, the ends either meanwhile growing by cell increase or having finally ceased likewise. Furthur development consists only in thickening of zoarial parts.

Cell increase and greatest zoarial growth takes place only at the apices of the frond and margin of the basal expansion, as in *Pachydictya*. The width of any branch or part depends mainly on the relative growth vigor at the apex in the building of that part. The thickness depends a little on vigor of axial growth but mainly upon age and cell lengthening. At the same time the solid margin extends, so that some width is added to that of the first growth. The initial parts appear to have been small, narrow, dichotomously branching. Some individuals dwarfed or matured at this stage. Others grew long branches, 2 to 8^{mm} wide, dichotomous or palmate digitate. Just below the forks the zoarium is widest, and there a macula appears on medium width branches or a row of maculæ continue down the middle on wider ones, or two to four rows on palmate parts.

The cells alternate in vertical rows. They are somewhat smaller in the initial than in the later zoarial growth stages, but as a rule the widths of the zoarium correspond to numbers of cells and cell rows. Increased number of rows is less by intercalation than by marginal addition at the side of the growing apex, and decrease is by reduction at the margin. Sometimes

a branch widened and narrowed repeatedly, but they usually grew uniformly for a great length. Branches are twisted, heliotropic.

This highly developed zoarium has equally modified cells. As in *Pachydictya* there is a mesial lamina or wall and the thin-walled, prostrate, short, axial parts of cells are in single series on either side, without mesopores, rectangular, or in part drawn out obliquely toward the zoarial margin. The peripheral cell part is sharply defined, both by obliquely outward direction and by a thick complex wall between autocell openings, which are thus a diameter or more apart. This wall comprises the cell walls which appear thin, and between them a mesopore space. In transverse and longitudinal thin sections one may see a tabulated mesopore followed by filled mesopore space, to which the cell walls are amalgamated on either side. What is most novel is a strong dark line or wall dividing the mesopore space. On the surface the mesopore space is elevated, rarely depressed, and the cell aperture rows are in furrows, separated by strong continuous longitudinal papillose ridges, and the apertures in each row by lower short transverse ones. The ridge may be double or again discontinuous, exceptionally. The ridges are the structural cause of the dark line or wall seen within the filled mesopore space. Maculæ have closer parallel ridges, and the zoarial solid margins may appear puncto-striate.

This structural development appears due to the chaining of zooids longitudinally, probably by a canal system which impressed the longitudinal furrows or troughs, causing the mesopore space to be relatively raised. These furrows end at the growing apices of the zoarium, where cells, respectively zooids, were increasing rapidly. As the growing apices became more remote from a given part or ceased, the furrows filled gradually, and a more allsided relation arose between the cells.

No mesopore calycals have been detected and the mesopore space being confluent with the cell calycals, and so far subordinated and fused to the autocell walls, one might conclude that

the corresponding zooids or other structure was reduced to virtually an interautozooidal cortex. Comparison with *Pachydictya*, however, shows the ridges, and corresponding internal structures to be mesopore walls in origin. The so-called tubuli seen in thin section, corresponding to surface papillæ, are then modifications of mesopore walls. The autocell walls proper have none. The so-called mesial tubuli are present. The autocell may have one or two tabulæ in the peripheral region, and at the upper angle, between the axial and peripheral cell, a small hemiseptum may appear.

Similar species to the above described as to frond, compose the genus *Stictoporella*, one of which is peculiar and further instructive:

Stictoporella cribrosa Ulr.[1] is bifoliate with branches about 2^{mm} in width, which bifurcate and anastimose rapidly, growing thus to a large broad frond with numerous oval so-called fenestrules (Plate B, Figs. 7, 8, and 9). The zoarial growth from cell increase is at the branch ends, the margins of the branches, *i. e.*, around the fenestrules very quickly becoming static as to cell increase, although with age the thickening from cell lengthening extends them, constricting or even closing the fenestrules.

Normally the downward end of the initial branch is pointed with striated solid beveled surface, which is supposed to have articulated into the crater-like socket of a striated non-celluliferous basal expansion, forming a movable joint. The wide-spreading zoarial branches coalesce with other zoaria of the same and different species so freely that this joint must have been usually immovable. When part of the zoarium died out, it was regrown by a laminar cell growth, or again fragments of a zoarium grew a new one, in which case a basal expansion unlike the first was developed, or again the fragment became the basal to a lateral fenestrated sporadic growth.

Cell increase is at the growing margin from a mesial plane, as in *Pachydictya*, but the prostrate thin-walled part of the cell is long, overlapping, so that in transverse section the axial

[1] This appears to be the *Clathropora flabellata* Hall!

region is four instead of two cells thick. As the cells turn into the peripheral region the walls thicken and distinct mesopores intercalate. The autocell has a saucer-shaped calycal at the surface and at its center a narrow cell-opening. The small cells or mesopores are either similar, especially in young fronds, or again have the cell opening and even the calycal filled solid, in which case the autocell calycals also become ill-defined, and the surface feature is that of small cell openings and broad rounded interspaces. This condition is the maturer stage. The mesopores are either few and the autocells subquadrangular or polygonal, or again mesopores are very numerous and autocells rounded. Large or small groups of mesopores forming maculæ occur in broader parts of the branches, and the 0.5^{mm} wide border has mesopores only. A constricted, closed fenestrule simulates therefore a macula.

The mesopores frequently differ in size and some of them appear to become autocells, peripheral cell increase thus existing, although necessarily to a limited degree, since the peripheral cells' length is only about equal their diameter.

Thin sections reveal no tabulæ in either autocell or mesopore. The thick walls are dense with a striping parallel to the surface calycal bottoms, *i. e.*, converging upwards to median wall. The mesopore openings are seen to constrict and close while their calycals fill, and then the increments of growth or striping cross them continuously, direct, or arched upward instead of downward across the mesopore space. In this case the amalgamation may be so complete that the appearance is that of one wall between autocell openings. This filling of the mesopore space contrasts with that of *Pachydictya* in that it is by laterally thickened vertical walls instead of by vertically thickened transverse tabulæ. Notably the results are very similar in the end.

In closed mesopore stage the zoarial margins become solid, smooth, or striated, and in the very few zoarial basal stalks seen the autocells also are filled on the surface above the beveled zoarial articulation. Ulrich describes moreover certain closing apercula over cell apertures at the bottoms of calycals, but their

occurrence is sporadic, probably incidental to dying off of the zooids, since these structures never occur within the cell opening as tabulæ, which they should if the zooids survived their formation. This species has no warts upon the walls and no "tubuli."

Ptilodictya (*Escharopora*) *subrecta* Ulr. is a simple bifoliate frond, or if divided the branches do not diverge. The zoarium is sword-shaped or feather-shaped, the point or lower end articulating to a crateriform, striated basal expansion. Specimens vary from 10 to 50^{mm} long, 1 to 10^{mm} wide, and 0.5 to 1.5^{mm} thick. In fossils the basal expansion is separate from the frond, and when living they could have united by a corneous interval or the cortex alone. The frond began evidently very narrow and grew by axial, apical cell increase, the growing end widening more or less and again narrowing somewhat, according to growth vigor. Marginal cell increase near, but below the apex also occurred in some, but the older parts have a solid margin. The cells have rather short prostrate thin-walled axial part and turn more or less sharply into the peripheral direction, the walls here thickening quickly. The cells are arranged, alternating in vertical rows (Plate B, Fig 10). They are at first quadrangular, but before reaching the peripheral region become hexagonal. Here the solid interspace, or wall, thickens, so that oval or subquadrate apertures remain, these being at the bottom of calycals which are confluent in longitudinal rows, or oblique rows in case of the cells that were added marginally. Sinuous, long ridges bound the cell rows (see figure). In later growth thickening, these ridges meet alternatingly at the sinuosities bounding rhombic calycals and finally change to continuous peripheries, the cell apertures becoming meanwhile somewhat larger, subhexagonal, except in the oldest zoarial part or stem where the furrows remain.

Thin sections show the cell walls completely amalgamated, the sinuous longitudinal ridges alone being evident. No tabulæ are seen, except one or two hemisepta. But the exterior of zoaria exceptionally show a few mesopore apertures, these being

in place of the furrows or again at the summit of monticules. The zoarium, if broad, is usually thickest medially, this part then having one, two, or three rows of monticules also. The thicker median part alone appears continued in the stem, which is narrow and thickened to nearly cylindrical form, tapering, ending with a beveled striated articulation area. The articulation area and supposedly the basal expansion grew *pari pasu* with the frond. In old specimens the stalk next to the articulation is solid surfaced, cell apertures having all closed over, except as to the confluent calycals or furrows.

Interpretation of this form from comparison with those described should include in the first place the suggestion that autocells which are evident are separated by completely subordinated mesopores, these being rarely evident, but really always represented in filled condition in the thick amalgamated wall. The confluence of the autocell calycals is explicable as due to the impress of a canal system which was developed strongest in vertical direction during cell increase at the apex; later an all-sided relation between zooids arising, except at the stem, where the basal expansion united. The articulation to the basal expansion shows the zoarium to have been in part non-calcareous. Again, since no pores or even "tubuli" are present, the closing up of all autocell apertures on the stem argues the cells evacuated by the zooids, except as to the calycals. The general manner of development of calycals argues the same.

The hemisepta require special mention. They have been said to have "doubtless served as supports for the movable operculum."[1] The said movable operculum is, however, unknown, and the word "doubtless" is unwarrantable. In fact, the hemisepta occur in some species beneath complete tabulæ, and in those cases they were isolated from the aperture. In *P. subrecta* no tabulæ intervene, and two interpretations may be admitted for sake of argument. The hemisepta occur one at the bottom and one at the top near the termination of the prostrate or axial cell, their position requiring no explanation

[1] Vide Text-Book of Palæontology, by C. R. EASTMAN, Vol. I, p. 279, l. 4.

except reference to some unknown particular cause if considered as accessory opercular processes. I shall add another hypothesis, viz., that they are reduced structures homologous with regular tabulæ similarly situated in other species, *e. g.*, *Pachydictya foliata* Ulr. Their position may be accounted for as related to the sharp turning of the zooid and its cell from axial to peripheral direction, and thus may be taken as evidence that the zooid evacuated the cell as it built. (See text Fig. 2, *A*, p. 169.)

Some smaller closely related species (*Arthropora*) are many-jointed, partly simulating, therefore, the following one. Very probably some cylindrical forms like this one should be considered as to origin as narrow bifoliate, and hence having become rounded.

Arthroclema armatum Ulr. consists of numerous small celluliferous jointed segments which formed a branched zoarium. Numerous primary segments form the main stem, from which lateral branches arise, these being composed of many secondary segments and bearing likewise lateral branches of tertiary segments. These hundreds of segments are each about 3^{mm} long, subcylindrical with generally six or five or four rows of cell apertures, six to ten apertures in a row. The primary segments are 1^{mm} or less in diameter, the others 0.5 and 0.3^{mm} or less.

Each primary segment has a small axial region in which the cells are prostrate, thin-walled, and angular, and a peripheral region which is thickened according to age. The small, rounded cell apertures are separated by solid, longitudinally furrowed interspace and a large prominence behind each aperture. Some of the apertures are closed by constriction near the articulation areas. The ends or articulation surfaces are solid-faced, respectively concave and convex, and the lateral articular socket, when present on a segment, is impressed in the peripheral solid wall. Thin section shows the walls thoroughly amalgamated, the peripheral region merely having striation parallel to the surface.

Secondary and tertiary segments are similar to primary ones partly developed.

A related genus, *Arthrostylus*, has the segments with four sides, one of which is without cell apertures but striated.

Rhombopora lepidendroides Meek. is strictly a cylindrical type. A small, thin basal expansion supports a long, branching, cylindrical stem about 2^{mm} in diameter. There is a central thin-walled axial region in which the polygonal cells may have one tabula, and there is a narrow, thick-walled peripheral region with narrow cell openings without tabulæ. The surface shows oval cell apertures at the center of calycals, these being arranged in transverse, vertical, and oblique rows, their margins being more or less in contact. The elevated interspace has rows of small warts, which divide the zoarial surface somewhat into rhombs, including each a calycal. Usually a second larger set of warts or acanthopores are situated at the junction of the rows. The internal wall structure corresponds, *i. e.*, the thin, dense walls of the axial region change quickly to thick in the peripheral region, with striation parallel to the calycal, interspace, and wart surfaces.

There is no distinct evidence of mesopores, but a simulation of maculæ and other characters in common with the forms of Trepostomata, genera *Batostomella*, *Eridotrypa Batostoma*, which they approach more closely than to other than cylindrical Cryptostomata, would indicate that the interspaces are mesopores rather than thickened autocell walls alone.

Phylloporina corticosa Ulr. belongs to the reticulate series, and has a reticulate frond and solid basal expansion (Plate B, Figs. 11 and 12). The frond is composed of so-called branches 0.5 to 1 or 2^{mm} wide, which anastimose laterally at somewhat regular intervals, producing elongate fenestrules. Each branch has cells on the obverse side, but none on the solid, smooth or striated reverse side. Thin sections show that the cells arise mesially, have a long, thin-walled, tabulated prostrate portion, then become more closely tabulated as they turn slowly into the peripheral

region. The axial cells overlap so as to be three or more deep in transverse section. The peripheral region is characterized by filled interspaces or mesopores which more or less completely separate the cells, the cell margins rising a little above the interspace at the surface. Zoarial growth as to cell increase took place only axially, *i. e.*, at the branch ends. The peripheral growth comprised thickening of the branches with cell lengthening on the obverse side and with about equally as thick, solid or rarely vesiculose increment on the reverse side, thus proving the branch to have been surrounded by a secreting cortex. Young branches usually have on the obverse a median keel, the edge of a wall or walls extending from the mesial line, and this E. O. Ulrich compares to the longitudinal ridges dividing cell rows in *Rhinidictya*. It bears a few acanthopores. An obtuse keel on the reverse produces no internal wall distinction. With age the keels disappear from the then rounded or flattened obverse and reverse sides, and the fenestrules constrict, even closing some of them. Branches are 1 to 2^{mm} thick.

The cell apertures are arranged in one or two rows on each side of the median keel, or a few more at inosculations.

The basal expansion is the key to the better understanding of this zoarium. To the description of it as "an expanded base," the following is added from specimens at hand: Basal expansion thin, incrusting, about 2 or 3^{cm} in diameter, the marginal or younger part bearing stellate monticules like those of *Stellipora* (*Constellaria*), *i. e.*, a central depressed macula with six to twelve rays, between which are as many sloping ridges of autocells. These monticules or stars are about 3^{mm} in diameter. The rest of the expansion is crowded with young stars between larger older ones of various sizes. It appears that the stars increase in size by addition of a few ridges, all of the ridges elevating rapidly at their proximate ends. When about 1^{mm} high they begin to anastimose, and they continue to grow and elongate upward, anastimosing and branching, whence arises the reticulate funnel-shaped frond, with cell apertures turned to the outside and a solid, striate surface on the inner side; the obverse side of the

branches arising from the celluliferous ridges of the monticule, the reverse solid surface continuing from the central macula, which has become solid or coarsely vesiculose, succeeding distinct mesopores, and forms the bottom of the funnel. The median keel of the obverse side is, again, the continuation of that of the ridge in the monticule stage, the same as appears in the ridges of stars on *Stellipora*. The arrangement of the cells on the branches originated likewise in that of the stars. The basal expansion bears one largest frond, two to five smaller ones, and several monticules of various degrees. The internal structure of the basal is more similar to *Stellipora* than to that of the frond or reticulate part of *Phylloporina*.

The grown funnels must have crowded each other, and in fact fossils evince irregular shape in their later stages. Some evidently met accident, since specimens occur in which a new growth arises from the broken edge of an older piece and in a new direction. Also, a secondary basal lamina may develop from the poriferous side of a fragment, bearing new somewhat regular stars or monticules. A fragment may convert itself into a single large monticule or new basal, and other variations occur.

The long cells with many tabulæ in *Phylloporina* are remarkably like those of Trepostomata. The basal expansion like a *Stellipora* and the development of the reticulate funnels from monticules suggests relationship with Trepostomata and not with bifoliate Cryptostomata. There is not then any relation between the *Stictoporella cribrosa* type of anastimosing branches and the similarly anastimosing parts of *Phylloporina*, which might better be called bars than branches to distinguish them.

Other truly reticulate forms probably derived from *Phylloporina* as E. O. Ulrich suggests.[1]

Septopora biserialis (Swal.) has branches or bars 0.8 to 0.3^{mm} wide, dividing laterally, and united at intervals by transverse processes called dissepiments, rather than anastimosing,

[1] EASTMAN, op. cit., p. 281.

the whole forming a fenestrated frond with primary branches or bars arising from an irregular basal attachment, and from these a little narrower, parallel to slightly radiating ones. The fenestrules are rather wider than the bars; ten bars occur in 1^{cm}. They have celluliferous obverse side and solid reverse, the latter on the outer or under side of the zoarium and forming the basal expansion and sometimes rootlike anchors at intervals above it. From the base a more or less funnel-shaped stalk supports the large frond on one side.

The cell apertures are about 0.13^{mm} in diameter and on the bars are arranged in two rows, separated by a thin median ridge which bears more or less prominent small warts or acanthopores. The dissepiments have distributed cell apertures only.

The internal structure seen by thin sections consists of short prostrate thin-walled axial cells arising mesially, turning sharply into the peripheral region where they become surrounded by interstitial solid deposit. Thus the cells have the appearance of being thin walled "enclosed in a calcareous crust," since the mesopore spaces on the obverse and the equally thick solid deposit on the reverse, surround the cells. There is a median wall or structure corresponding to the median ridge. The reverse is longitudinally striated at first, later nearly smooth, and its internal structure corresponds thereto. Further, it has been claimed that the solid deposit on the obverse and reverse had small vertical pores ending in minute warts at the surface, but that the dim structures so interpreted were open tubes may well be doubted. Another feature, the so-called dimorphic pores (cells), arise in the solid deposit of the reverse and obverse, are somewhat smaller than the regular cells but at the surface end with slightly elevated peristome like these. They are not to be wondered at, since they arise in what is homologous to mesopore space in, for example *Stellipora* or *Stictoporella*, and may be taken as evidence that peripheral cell increase had not wholly disappeared. The cells have no tabulæ, but sometimes a hemiseptum.

The dissepiments in this zoarium are comparable both to

drawn out inosculations from which they may have arisen and to side branches to which they are tending. The relation of obverse and reverse of the frond is a little strange, since they are reversed as compared to *Phylloporina*, the basal expansion also being unlike in that genus; differences which I cannot explain, but yet are of small import since closely related genera as *Fenestella* and *Semicosmium* differ in just that way. I feel not assured that the primary basal expansion is known except in *Phyllopornia corticosa* Ulr.

DISCUSSION OF CRYPTOSTOMATA.

These described species may suffice to represent the Cryptostomata. The species of *Pachydictya* and *Rhinidictya* are of the Rhinidictyonidæ; *Stictoporella* and *Ptilodictya* of the Ptilodictyonidæ; nothing especially different is seen in the Cystodictyonidæ except sometimes a lunarium like that in the Trepostomata; *Rhombopora* is of the Rhabdomesodontidæ; *Arthroclema* of Arthrostylidæ; *Phylloporina* of Phylloporinidæ; *Septopora* of Acanthocladiidæ; and the Fenestellidæ are merely distinguished from the latter by having dissepiments without cell apertures on them. In these all, and those which they are taken to represent, the growth is acrogene and cell increase is almost all axial. Axial and peripheral regions are sharply defined, cells short, and mesopores filled more or less solid.

The Cryptostomata differ in degree of specialization of structures rather than in kind from the Trepostomata. In fact, they are arbitrarily divided in all respects. The defined axial and peripheral regions of zoarium appearing to arise in Trepostomata are merely as strongly to stronger developed in Cryptostomata. So also are the long, tabulated cells changing to shorter, with or without tabulæ and so-called hemiphrams or hemisepta. Peripheral cell increase is only reduced to nearer the minimum. The mesopores begun apparently as young cells in Trepostomata and developing to subordinate special structures or vesiculose to solid interstitial filling, are vesiculose to solid in Cryptostomata. Monticules ranging to the extreme

from called maculæ in the former are represented by maculæ in the latter. Indeed, sharply defined peripheral region, short cells, reduction of tabulæ, hemiphrams, filled vesiculose or solid mesopores, and solid maculæ, so-called acanthopores, and mesial lamina, lunarium, etc., are found in highly specialized Trepostomata of the Fistuliporoid type.

There is no character in Cryptostomata that distinguishes them all from Trepostomata. The former comprises essentially certain families of highly modified zoaria related to Fistuliporidæ of Trepostomata. They are not a single branch from these, but three or more, as seen when examples like *Pachydictya*, *Rhombopora*, and *Phylloporina* are compared. The genera named are the Cryptostomata, which are scarcely separable, if at all, from Trepostomata, but are not related one to the other as closely as to Trepostomata. They compare back to *Cramophylla*, *Eridotrypa* and *Stellipora* respectively, which belong to three different recognized families of *Trepostomata*. They belong to more than distinct families, to three divisions of Cryptostomata, the frondiferous, cylindrical, and reticulate respectively. The highest differentiated Cryptostomata, also, for example, *Ptilodictya* and *Fenestella* unite to not the same Trepostomata-like Cryptostomata. The question should be rather on the propriety of dividing the Monticuliporoidea at all than on the probability of Cryptostomata and Trepostomata belonging to different phyla.

As to the interpretation of the zoarium of Cryptostomata, the entire skeleton, excepting the under side of the basal expansion, was covered by some kind of cortex uniting the zooids, as proved by deposits of superimposed laminæ in intercellular spaces, on solid margins, and on the reverse surfaces. The zooids built and evacuated the cells, resting more upon than in them at maturity, as proved by tabulæ close to the aperture, by closed-up autocells, as in the stem of bifoliate zoaria, and by the building of skeleton exclusively at its outer surface. Subordinated zooids, in some degree of development, were always present, since mesopore spaces, distinct or filled, are always present in the peripheral region. Solid maculæ, solid zoarial

margins, and solid obverse of reticulate ones are mesopore areas being seen sometimes as such (*e. g.*, *Stictoporella*, *Phylloporina pars*, *Semicosmium*), and are probably all really maculæ covered by subordinated zooids, or at least a cortex. Longitudinal median ridges and walls arise variously. Again, in jointed forms (*Ptilodictya*, *Arthropora*, *et al.*) part of the skeleton was not calcareous. These show reduction from the entirely calcified zoarium, and also the filling up of mesopores and some autocells might be readily interpreted as due to leveling down of division walls between zooids: a process of reducing thin-walled cell mass to a solid axis within a living cortex.

A quite different interpretation from that just given is expressed in the current definitions of Cryptostomata. Vine[1] defined them, "Zoœcia tubular, subtubular, in section slightly angular. Orifice of cell surrounded by vestibule, concealed." He does not speak of tabulæ, mesopores, acanthopores, etc., and only later knowledge, especially by E. O. Ulrich, has changed the definition, adding to *vestibule*, "which may be intersected by straight diaphrams or hemisepta owing to superimposition of layers of polypides," "surrounded by vesicular tissue or solid calcareous deposit." Vine, having in mind such as *Septopora* and *Ptilodictya* without tabulæ, seems to consider the cell as a permanently occupied zoœcium; Ulrich includes the richly tabulated *Pachydictya*, *Phylloporina*, etc., and speaks therefore of superimposition of polypides or zoœcia. More direct interpretation would indicate each cell to have been gradually built and evacuated by one zooid, as argued in the preceding pages. For corresponding explanation of hemisepta see text, p. 161.

The separation of Cryptostomata from Trepostomata is scarcely tenable, and they may be discussed together. The zoarium of Cryptostomata is merely the more differentiated, the simplest Trepostomata and the typical Cryptostomata being extremes in the same line. This developmental series might well be compared to the reduction of thin-celled Tabulate corals

[1] Brit. Assn. Rep., 1883, p. 184.

to a solid axis,[1] details of which may be omitted here, since there is no character in Cryptostomata as also in Trepostomata negative to supposed relation of Monticuliporoidea to Tabulate corals as already discussed, unless, as said, their relation to Bryozoa can be proved.

In comparing to Cylostomata to which Cryptostomata have been sometimes referred, *Stomatapora* and *Berenicea* come first into consideration. Vine referred them to Cryptostomata in

AFFINITIES OF MONTICULIPOROIDEA.

FIG. 2. Diagrams showing: *A*. Interpreted origin of inferior and superior hemiseptum. *a*, axial cell stage; *b*, turning stage; *c*, peripheral stage, hemisepta remaining at points where the relation of zooid and its cell changed most. *B*. *Proboscina minnesotensis* Ulr., transverse section. × 40. *C*. Relation of zooids of Bryozoa to their cells, for comparison with *D*, the interpreted relation in Cryptostomata. *a*, tabulated cell as in *Pachydictya*; *b*, cell with hemisepta as in *Ptilodictya*; *c*, cell closed by wall-thickening as in same.

fact. These genera comprise essentially the Paleozoic Cyclostomata, and range from Ordovician to Recent times. *Stomatopora* (*e. g.*, *S. inflata* H.) forms branching single series of club-shaped prostrate free cells, each arising from under the anterior, larger end of the preceding one, and having a small circular aperture on the anterior upper side. Its walls are said to be minutely porous if well preserved. *Stomatopora* is not comparable to any of the Monticuliporoidea, but is a key to species called *Proboscina* or *Berenicea*.

Proboscina minnesotensis (Ulr.) forms two, three, or more series of prostrate cells, each arising from under the anterior of the preceding cell of its series. The anterior end is drawn out upwards, making a vestibule, as it is called, bearing the round aperture. The cells appear superficially as immersed in a band of stereom, but thin sections show only compacted, thin-walled

[1] *Pachypora*, *Corallium*, etc., see Neues Jarb., Beilb. X, p. 306–312.

cells (text Fig. 2, *B*), the alternating apertural ends being rounded, the other cells at that point being appressed, angular. The walls are poorly preserved as compared to fossil brachiopods and corals upon which they have grown, but very probably the basal side of the cell only was porous. Sometimes the bands or branches become very wide, thus approaching nearly *Berenicea* proper, in which perigene growth, like that of incrusting monticuliporoids is simulated. Since *Stomatopora* and *Berenicea* include also Recent species, their position as Bryozoa is established. The serial relation of other Cyclostomata and the rather similar zoaria of Chilostomata are further well shown in handbooks, and will not be discussed here.

In comparing *Berenicea*, including *Proboscina*, one at once notes that there are no tabulæ, no monticules or maculæ, no mesopores, no thick walled region, that the apertural vestibules are free and cell walls perforate. Monticuliporoid cells have imperforate walls. Further, all monomorphic monticuliporoids are again different, having without exception apertures of cells crowded together. Dimorphic forms with tabulæ are also to be excluded, while dimorphic, short celled, non-tabulate forms may be admitted to closer comparison. In fact, such as *Protocrasina* (Eastman, *op. cit.*, p. 262, Fig. 417) appears to be, might be bryozoon or monticuliporoid as to its outward aspect, the nature of its walls as poriferous, thin, or dense, thick, being the determining difference. But the comparison requires the Cyclostomata to be viewed as derived from highest specialized Monticuliporoidea, the dense autocell walls of these to be explained as having become porous in *Berenicea*, *et. al.*, and the thick, solid mesopore spaces reduced to a minimum, and thus at once a weak chain of hypotheses or an arbitrary definition is required to unite the nearest Bryozoon, *Berenicea*, to Monticuliporoidea.

Other Cyclostomata differing from *Berenicea* in changing the prostrate growth into bifoliate, acrogene, or massive form, and the cell apertures and vestibules from free to more or less in contact as in *Osculipora*, *Aspendisia*, etc. (Eastman, *op. cit.*, pp. 264–265), resemble thereby such monticuliporoids as *Stellipora*,

Septopora, etc., but only superficially. The Cerioporidæ (*op. cit.*, p. 266) most resembling Trepostomata have porous walls and are in the second place not well determined. If viewed as derived from Trepostomata the walls being assumed as having become porous — an admissible hypothesis — this hypothesis requires a reverse view of the evolution of Cyclostomata from the first one, *i. e.*, that the long tabulated cell, not the short open one, is the more primitive in Bryozoa.

The same differences disunite Chilostomata as Cyclostomata from the Monticuliporoidea, where also their outward appearance is similar, as for example *Retopora* (*op. cit.*, p. 289) and *Septopora*.

The greatest importance rests on the interpretation of the zooid's position with reference to the cell. In Bryozoa the zŏoid inhabits closely the cell. In order to refer Monticuliporoidea to Bryozoa it appears essential that the zooid be considered as occupying the cell and Vine has so interpreted in his definition of Cryptostomata, as said. In cells without tabulæ of some species the interpretation might appear logical (*e. g.*, *Ptilodictya*, except on the stem) but other species have tabulæ (*e. g.*, *Phylloporina*), whence the interpretation of superimposition of zoœcia and of zooids. This interpretation then unfortunately assumes that which most requires proof. If there is anything clear in Monticuliporoidea it is that the cell is the unit structurally in every zoarium, that loculi between successive tabulæ can not be coördinated as such units because of inconstancy alone. They vary in length and breadth ratio from 1 × 10 to 10 × 1 and more, in the same zoarium. The interpretation of loculi as zoœcia precludes all uniformity of size and shape of zoœcium. In fact, the loculi are not described as structurally units in any species — but the cell. In the definition of orders only the successive loculi have been called zoœcia, an interpretation that is simply not supported by any evidence from the zoarial structure.

Interpreting the cell, not its loculi, as the zoœcium a great difference is at once evident between Bryozoa (text Fig. 2, *C*) and Cryptostomasa (Fig. 2, *D*) and Monticuliporoidea in general in the position of the zooid — a matter of greater importance

than tabulæ, hemisepta, acanthopores, communication pores, etc. Moreover, tabulæ characterize the Monticuliporoidea and true pores the Bryozoa. One cannot assert that no bryozoons have tabulæ but they probably do not. The superimposition of cells frequently occurs in monticuliporoids and in bryozoons, but forms a recognizably distinct structure from that of the tabulated cell proper. One finds, again, many descriptions of pores in Monticuliporoidea but none recognizably like those in Bryozoa, which run direct, transverse, through the cell wall as communication pores. The supposed pores parallel the cell walls and do not end in the cell, and if they were demonstrably pores, their difference would rather serve to separate the group from true Bryozoa. They are not pores in most cases. In case of the reticulate cryptostomata one might not wish to deny that pores could exist, but yet their existence is notably only in the mesopore space or outside the autocell wall, and might be interpreted like the minute porousness of some corals (Tubipora) due to living cells remaining in the stereom, rather than as canals.

SUMMARY

Briefly reviewed the Monticuliporoid zoarium consists, in the first instance of monomorphic tabulated cells, differing from the extinct *Chaetetes* corals in the cell increase being less often by fission than budding. In the second instance, the young closely tabulated cells develop with a retarded or mesopore stage preceding full size growth. In the third, many cells appear to be permanently mesopores, autocells however arising from mesopores. Some autocells displace several mesopores in their rapid growth expansion and the mesopores are either distinct or their bounding walls imperfect and tabulæ vesiculose. This development and its minor features is paralleled in living and fossil Alcyonarian Tabulate compound celled corals. In the fourth instance the cells are shortened, and the mesopores or interstitial space filled solid either by superimposed tabulæ or by thickened bounding walls: cells with few or no tabulæ or filled: Cryptostomata.

There is an accompanying differentiation from uniformity in the first instance to marked axial and peripheral region of the cell in the fourth and other characters incidental therewith. But all things considered the monticules and their special form maculæ, are all that separate the Monticuliporoidea from other Tabulate (Alcyonarin) corals, but apparently not from certain living Alcyonaria, which have possibly descended from them.

As to Bryozoa, two hypothetical comparisons with Monticuliporoidea are to be considered. First, the Cerioporidæ including *Heteropora*, may be Bryozoa derived from Monticuliporoidea in the first instance just mentioned, the solid wall having become porous with transverse canals. Secondly, Berenicea and other Bryozoons with more or less free vestibules might have derived from the fourth instance, being then a fifth stage or instance, the mesopore solid filling having reduced to nothing and imperforate cells walls having become perforate.

The Monticuliporoidea are difficult to separate from corals in two concordant instances. In two instances in which their structures nearest approach the Bryozoa, they separate easily or rather are difficult to unite with them, and of these instances the one probably negatives the other.

EXPLANATION OF PLATE B.

FIG. 1. Pachydictya foliata, frond natural size.
FIG. 2. Pachydictya foliata, longitudinal section. × 10.
FIG. 3. Pachydictya foliata, tangential section. × 10, showing cell pattern.
FIG. 4. Rhinidictya mutabilis, frond of an undersized individual.
FIG. 5. Rhinidictya mutabilis, part of surface. × 20, after Ulrich.
FIG. 6. Rhinidictya mutabilis, longitudinal section. × 10.
FIG. 7. Stictoporella cribrosa, lower part of frond with articulation.
FIG. 8. Stictoporella cribrosa, surface. × 20.
FIG. 9. Stictoporella cribrosa, longitudinal section. × 20.
FIG. 10. Ptilodictya subrecta, surface. × 20 showing zoarial margin.
FIG. 11. Phylloporina corticosa, part of basal expansion and one frond. × 2.
FIG. 12. Phylloporina corticosa, longitudinal section. × 20.

FREDERICK W. SARDESON.

MINNEAPOLIS, MINN.,
November 5, 1900.

STUDIES FOR STUDENTS

THE STRUCTURE OF METEORITES. II.

(Continued from page 66)

CHONDRITIC STRUCTURE

This characterizes the great majority of stony meteorites, and being peculiar to meteorites will be described in detail. Of the 314 stone meteorites listed by Wülfing in his recent classification, 288 are more or less largely composed of chondri. Some meteorites are composed of chondri almost exclusively (Borkut) while others contain them imbedded in a groundmass. The latter may be tuffaceous, glassy or crystalline. The term chondrus, plural chondri, is from the Greek χόνδρος, a grain, the term being applied in reference to the size and shape of the body. Some writers prefer the diminutive form of the word, viz.: chondrules. In size chondri may vary from that of a walnut to a dust-like minuteness. The larger number are about the size of millet seeds. The form of chondri is generally spheroidal, but varies from essentially spherical to mere irregular fragments. Some chondri are flattened or oval and others show apparent deformation subsequent to their origin. In the latter, depressions or projections occur which often look as if a hard chondrus had pressed against another soft one during the process of formation. The deformed chondri pass by every gradation into those which appear to be rock fragments with rounded angles. The surface of the chondrus is rarely smooth, being usually rough or knobbed. From many friable meteorites individual chondri can easily be isolated, but if the meteorite is at all coherent the chondri break with the rest of the mass. The color of chondri is usually white or gray, but some are brown to black. As they are often of the same ingredients as the groundmass in which they are imbedded

they may differ little in color from it. On this account and on account of an ill-defined contour they may be overlooked and a crystal may be considered porphyritic, which is really part of a chondrus. Usually, however, the chondri are plainly marked

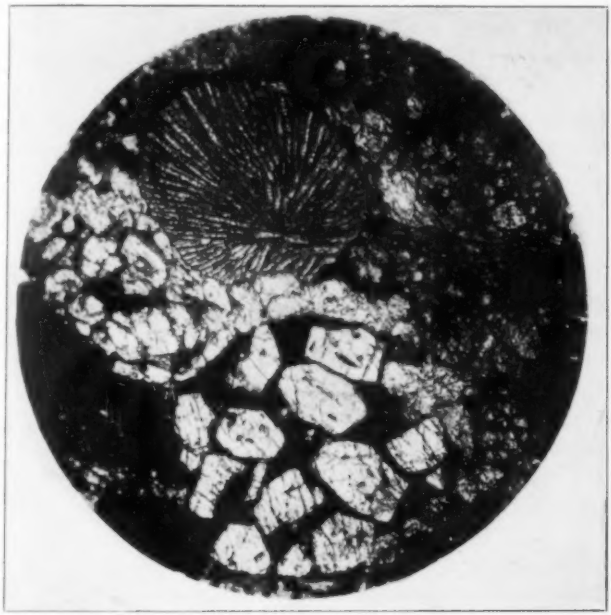


FIG. 7.—Section of the Homestead meteorite, showing a typical eccentrically-radiating bronzite chondrus (above) and a porphyritic chrysolite chondrus (below). A granular chrysolite chondrus also appears at the left. × 65. After Tschermak.[1]

on a polished section by differences in color and contour. In structure chondri may themselves be granular, porphyritic, coarsely or finely fibrous. They may consist of a single crystal individual, in which case they are said to be monosomatic, or of several individuals, when they are said to be polysomatic.

[1] Die mikroskopische Beschaffenheit der Meteoriten. Tafel VII, Fig. 4. Figs. 2, 3, 4 and 5 of Article I should also be credited to Tschermak, Lehrbuch der Mineralogie, 4th edition, p. 585.

True monosomatic chondri are confined almost exclusively to the mineral chrysolite. They can be known by their simultaneous extinction in polarized light. Polysomatic chondri may be made up of different minerals as well as different individuals and may show more than one kind of structure, *i. e.*, a chondrus may be granular in one portion and fibrous in another. The following minerals are noted by Tschermak as forming chondri, their relative abundance being in the order named: Chrysolite, bronzite augite, plagioclase, glass, and nickel-iron. This order, it is to be noted, is also that of the fusibility of the minerals, the most infusible and hence the earliest cooling mineral forming the most chondri. Chrysolite chondri usually contain large quantities of glass of a dark brown color. This may be arranged (*a*) in the form of alternating layers, in which case a marked rod-like or lamelliform appearance is produced, or (*b*) may form a base in which the mineral is developed porphyritically, or (*c*) may occur in the center of a crystal, or (*d*) may form a network. Polysomatic chondri of the latter sort are especially liable to be mistaken for those of bronzite since they simulate the fibrous appearance of the latter. Occasionally the crystallization may have proceeded only far enough to produce skeletal or branching growths of the mineral among the glass. Both monosomatic and polysomatic chrysolite chondri may have the arrangement of a well-marked rim about a spherical interior. This rim may, in the polysomatic chondri, be composed of many individuals. Such a rim is often dark from a content of iron and troilite. Chromite, either in minute grains or in dust-like aggregations, also forms a common inclusion usually near the surface of the chondrus. The quantity of opaque inclusions may be so great as to give the chondrus a black color. Such chondri associated with those of light color are to be found in the stones of Knyahinya, Mezo-Madaras and others. The constituent minerals of such chondri are chiefly chrysolite and bronzite. Bronzite chondri are usually of a finely fibrous character. The fibers instead of radiating from a center as do those of spherulites usually radiate from an eccentric point. This eccentric arrangement constitutes one of

the most marked features of the chondri and separates them sharply from any formation seen in terrestrial rocks. The bronzite chondri have less glass than those of chrysolite. Monosomatic chondri of bronzite have never been observed, the large

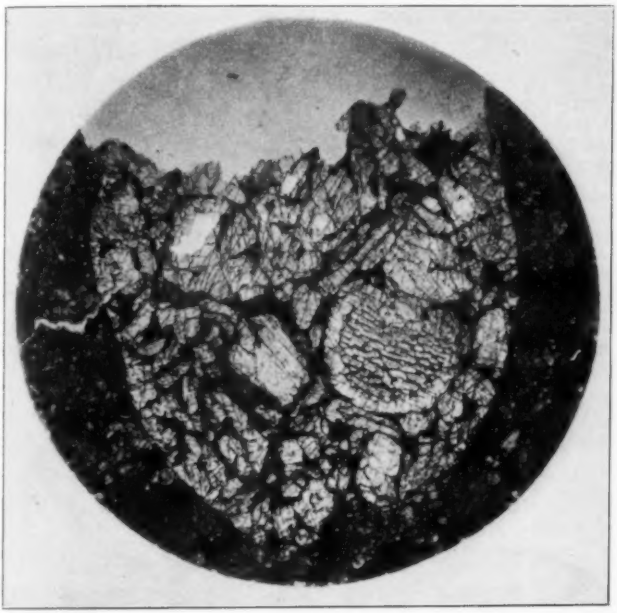


FIG. 8.—Section of the Dhurmsala meteorite, showing a large, somewhat porphyritic chondrus enclosing a smaller monosomatic one. Both are composed of chrysolite. × 8. After Tschermak.[1]

crystal individuals showing, as a rule, no tendency to a spherical form. Besides bronzite chondri having an eccentric arrangement of fibers there occur those which are confusedly fibrous, and these may pass into those which have a netted appearace from crossing fibers. Such chondri, cut at right angles to the fibers, show the fibers to have a concentric arrangement. The

[1] Op. cit. Tafel VIII, Fig. 1.

chondri already mentioned, which are granular in part and in part fibrous, are usually made up of the two minerals chrysolite and bronzite. These minerals may be present in about equal quantity or either may be in excess. Usually the bronzite together with glass appears to occupy the intervening spaces between the chrysolite grains, indicating that it is of later formation. Augite chondri are not common but occasionally occur. They often show a structure which indicates repeated twinning. The mineral may appear also in the form of grains, usually of a green color. These grains can be distinguished from chrysolite by their behavior in polarized light. Chondri containing plagioclase in any large quantity are also rare but have been observed by Tschermak in the stone of Dhurmsala. The plagioclase alternates in bands with chrysolite and is in excess. Chondri also occur which are composed almost exclusively of glass, the only indication of the presence of other minerals being in the presence of forked microlites which may be referred to bronzite. Occasionally these microlites are of a pronounced star-like form. Chondri, or at least rounded spheres of nickel-iron, occur in some meteorites, though they are not common. All gradations occur from chondri which contain grains of nickel-iron to complete spheres of nickel-iron. In the stone of Renazzo such spheres have a covering of brown glass. Some of the spheres or rounded fragments also contain troilite, but troilite of itself never has been seen to form chondri. A more or less complete rim of metal is a characteristic of many chondri. The metal may occur in the form of rounded grains or as a continuous periphery. It has been suggested by Daubrée that such a rim shows that the chondrus has been subject to the reducing action of hydrogen. Besides the chondri colored black by inclusions of iron and troilite, as previously described, black chondri, which consist chiefly of maskelynite or granular plagioclase, occur in the stones of Alfianello, Chateau Renard and others. These chondri are transparent and colorless about their rim, but in the interior are totally black from inclusions of angular rounded grains, some of which are shown by their brown color to be

troilite. A gathering of grains at the center distinguishes these chondri from those previously described in which the rim was black. Besides complete chondri, fragments representing various proportions of a complete chondrus occur. These may, on

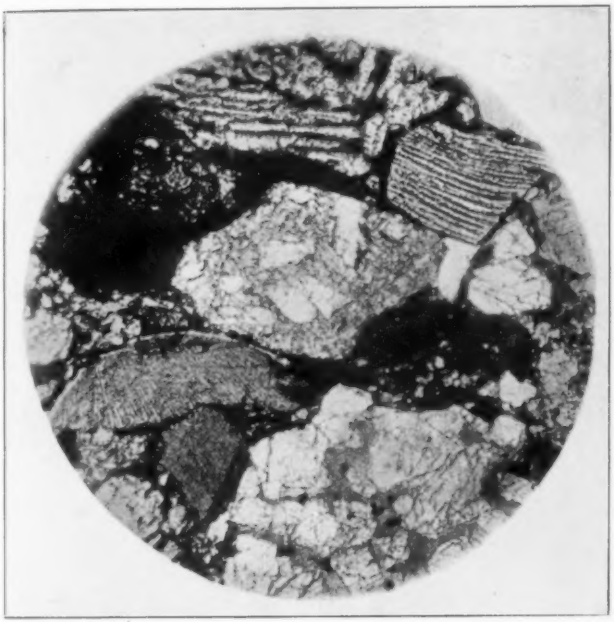


FIG. 9.—Section of the Mezo-Madaras meteorite, showing a meteoritic tuff made up of fragments of chondri. Portions of bronzite, chrysolite and nickel-iron chondri can be recognized. After Tschermak.[1]

account of their shape, be very misleading, as they may be taken for porphyritic individuals or for portions of a foreign stone if their previous chondritic origin is not recognized. Tschermak states that fragments of chondri are most numerous in the stones whose chondri have well-marked contours. So far as the association of chondri is concerned it is to be noted that chondri of more

[1] Op. cit. Tafel XIX, Fig. 4.

than one of the kinds above described usually occur promiscuously scattered through the same stone. There is no gathering of them into groups according to the minerals they contain. Occasionally one chondrus encloses another, and still more rarely two may be joined together. Broken fragments of chondri commonly occur in the same stone with complete chondri. Two fragments of the same chondrus are, however, rarely if ever found in juxtaposition. Hence there must have been considerable separation of the fragments before consolidation of the stone took place.

Theories of the Origin of Chondri and Chondritic Structures.—The conditions which have brought about the formation of chondri are not well understood, though the question has been much discussed and various hypotheses have been suggested. The views of earlier observers were to the effect that the chondri represented fragments of preëxisting rock which, by oscillation and consequent attrition, obtained a spherical form. Sorby regarded them as produced by cooling and aggregation of minute drops of melted stony matter. Tschermak considers their origin similar to that of the spherules met with in volcanic tuffs which owe their form to prolonged explosive activity in a volcanic throat breaking up the older rocks and rounding the particles by constant attrition.

Different views are, however, held by Brezina, Wadsworth, and others, these believing that the chondri have been produced by rapid and arrested crystallization in a molten mass.

Objections to theories of the first class are to be found (1) in the fact that the chondri usually have rough-knobbed surfaces instead of smooth ones, such as attrition might be expected to produce; (2) in the regularly eccentric form of most enstatite chondri, which attrition would be likely to destroy; and (3) in the fact that fragments of a preëxisting rock ought to show the constitution of the rock as a whole instead of specialized structure. Objections to theories of the second class are to be found chiefly in the clearly fragmental nature of most chondritic meteorites. It is in their variation from the surrounding ground

mass and in the eccentric arrangement of their fibers that chondri differ chiefly from the spherulites of terrestrial rocks.

SUPERINDUCED STRUCTURES

Several structures occur in meteorites which have apparently originated subsequent to the consolidation and solidification of

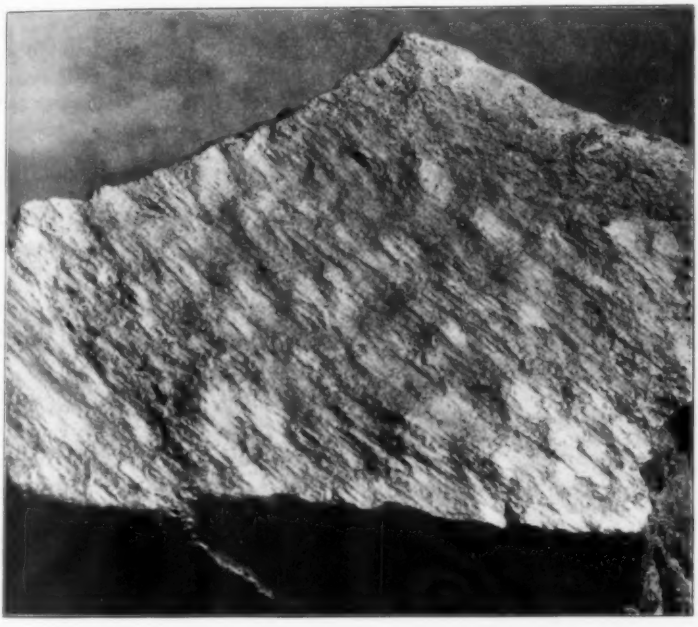


FIG. 10.—Slickensided surface, Long Island meteorite. Natural size. From a specimen in the Field Columbian Museum.

the mass as a whole. These may be enumerated as (1) slickensides, (2) faults, (3), bent plates, (4) veins, and (5) cleavage and joints. The first three may be grouped under the head of evidences of preterrestrial movement, but it should be stated that some authorities regard all these structures, including veins, as of terrestrial origin.

Slickensides (*Harnisch flachen, Surfaces de frottement.*)—These may be observed on portions of many meteorites, of which the following may be mentioned among others: Bath, Kesen, Limerick, Lixna, Long Island, Manbhoom, Mocs, Ochansk, Ställdalen, Tysnes Island, and Zavid. The slickensided surfaces may vary in area from a few square millimeters to those more than a foot square (Long Island). In many cases the surfaces have exactly the appearance of similar ones in terrestrial rocks, being smooth, shining, somewhat uneven, and more or less striated in the direction of movement. In other cases, however, they appear as dark striations on the contact surfaces, or as if the surfaces had been rubbed with a piece of graphite. The slickensided surface may be a broad peneplane with generally parallel striae, or it may be seen penetrating the meteorite in numerous narrow peneplanes following the same general directon at different levels. The surfaces do not always extend in the same direction, however, but in different directions and occasionally nearly at right angles to one another. One surface on the Long Island meteorite has in cross section the shape of a J. The polishing of the surface by the movement which has taken place often brightens the metallic grains so that they shine. Sections cut perpendicular to a slickensided surface show a flattening or elongation of the metallic grains, and even of other minerals along the course of movement,

Meunier regards the blackening seen on the surfaces as indicating heat developed by the movement, and states that the heat was sufficient to metamorphose a portion of the Mexico meteorite included between two slickensided surfaces, which he examined. The slickensided surfaces examined by the writer, however, give no evidence that the movement has been accompanied by any high degree of heat, at least enough to produce fusion, for the mineral grains along the surface are simply sharply cut off without alteration. This fact, together with the analogies given by terrestrial slickensides, indicate that the movements which gave rise to the slickensides must have taken place while the constituents of the rock were solid.

Faults.—Evidence of movement along a plane sufficient to produce well-marked faults in meteorites is not abundant. The slickensides already described prove slight movement, but how much, so far as the stony meteorites are concerned, it is difficult to say on account of the absence of bedding planes and other criteria of measurement. In the iron meteorites, however, the bands of the Widmanstätten figures afford a means of measurement. Sections of several such meteorites, viz., Bridgewater, Carlton, Magura, Puquios, and Descubridora, in this way exhibit faulting. In the Puquios meteorite the faulting is of somewhat complicated character, the kamacite bands showing slight dislocation in various directions. The largest fault extends the entire length of the mass, and has a throw of ⅛ of an inch (3 mm). Some crushing and branching also appears along this line of faulting. Other less extensive lines of faulting occur. The amount of throw seen in the Descubridora meteorite is more extensive than in the Puquios, being a distance of from ¼ to ½ an inch (6 to 12 mm). Owing to the toughness and tenacity of iron meteorites at ordinary temperatures, Howell has suggested that such faulting could only have been produced when the mass was highly heated, as, for instance, in its passage near the sun. He found that a piece of the Toluca meteorite, although very tough when cold, would crumble under the hammer when heated to a white heat. He states that it also seems necessary to assume a contact with some other body, as well as a heating, in order to account for the faults. In opposition to this view by Howell the faulting is believed by Brezina, according to a label in the Vienna Museum, to have been the result of the impact of the mass on the earth.

Bent plates.—These are somewhat allied to faults, there having been differential motion in the mass, but not a sufficient amount to produce fracture. Naturally, they are to be noted only in the iron meteorites. Carlton, Glorieta Mountain, Jamestown, Ranchito, and Toluca are some of the meteorites in which they have been observed. The bent plates appear upon an etched surface as curved Widmanstätten figures. They

never characterize an entire mass, so far as I am aware, but only portions, and occasionally but a small portion of a single mass. The amount of curvature is not great, rarely if ever exceeding 10^{mm} in 50. A single plate never has more than one direction of curvature, though it is often straight for some distance at one end and curved at the other. With reference to each other, however, the directions of curvature of individual plates may be quite different. Like faults, the bending is referred by Brezina to the result of the impact of the meteorite upon the earth.

Veins (*Adern, Filons, Veines*).—These occur in many stony meteorites, in fact in a sufficient number to characterize seven of the thirty-seven groups into which Brezina divides stony meteorites. The veins may vary in width from a mere line to 19 millimeters (Mocs). An even greater dimension is indicated by the size of single stones from the Pultusk and Mocs showers, which seem to be of a substance like that of the veins. The veins penetrate the stones now in a nearly straight direction and now in a more or less tortuous one. Sometimes they are single, then again branched, and again ramify to such an extent as to form a network. They are rarely uniform in width for any appreciable distance. On the contrary, they widen and narrow very irregularly, often forking so as to enclose portions of the mass and then meeting again. The Bluff meteorite shows two systems of veins crossing one another at angles of about 45°. The narrower of these is uniform in width and was observed over a plane 4×15 inches in extent. The wider varies much in width and is less extensive.

In color, veins are dark, usually black. The substance filling them is black, opaque, brittle, and of a semi-glassy character. In polarized light it appears amorphous and isotropic. It often includes splinters of the adjoining stone and little spheres of nickel-iron and troilite. Along the walls are often seen delicate metallic foliae, lying parallel to the direction of the veins. These appear in cross section like delicate threads. From the nickel-iron grains threads often run out in a direction

across that of the vein, and these may pass into empty clefts. In many portions of the stone of Chantonnay narrow, irregular, open fissures occur. Some of these have begun to be filled by matter that has flowed in from the surface, but it has penetrated only to a depth of a few millimeters. The vein substance

FIG. 11.—Cross section of a vein of one of the Mocs meteorites. The vein mass appears as a broad black band through the center. It is in part intermixed with the adjoining groundmass and in part has well defined walls. The gray spots are spheres and lumps of nickel-iron illuminated by reflected light. The branching of some of these into clefts, one of which is still open, is of interest. × 20. After Tschermak.[1]

usually has fairly well-defined walls, but on the other hand may gradually pass into the body of the meteorite. In the stone of Goalpara, which is coarsely porous, a black, vein-like substance forms the walls of the pores, makes up the groundmass, and

[1] Op. cit. Tafel XXII, Fig. 2.

penetrates into the minutest fissures. Again, the groundmass of the stone of Richmond is a black, half glassy substance which occupies the spaces between the chondri and spreads itself into their interstices. Thus the veins may occur as mere apophyses of a black groundmass. In fact, apparently the same substance forms veins in the meteorites of Mocs, a cement in the stone of Orvinio, and the entire groundmass of such carbonaceous meteorites as Cold Bokkeveld. That the substance is exactly the same in all these cases cannot be regarded altogether proved as yet, however. An analysis by Whitfield of the vein substance of the Bluff meteorite showed it to be very similar in composition to the mass of the stone. Tschermak states that the vein substance of the Goalpara stone consists of a network of iron, holding troilite, carbon, and a glassy substance found to be decomposed by acids. The substance of the black veins of the Chantonnay meteorite Meunier regards as consisting of a silicate of iron. An interesting experiment performed by him in this connection was that of heating meteorites of the group to which he gives the name of Aumalite, to redness without access of air. The meteorite then became black, of lighter specific gravity, and increased in hardness and toughness. In other words, it became a substance which he regards as exactly similar to that of the veins of Chantonnay. He regards the presence of this substance in the stone of Chantonnay, therefore, as proof that the meteorite had undergone heating or metamorphism before its entrance into the earth's atmosphere.

So far as the general appearance of the black veins is concerned, it may be said with Tschermak that they give the impression that the substance of the meteorite at some time underwent fissuring and that a fused liquid was absorbed into these fissures. The phenomenon must have differed somewhat from that of the injection of fused lava into the interstices of terrestrial rocks, since the substance of the vein mass agrees so closely in composition with that of the substance of the meteorite.

Vein-like filaments.—In passing from the iron to the stony

meteorites every gradation may be traced from metallic masses in which the silicates appear as porphyritic ingredients, through those appearing to be made up of interwoven constituents, to those in which the metallic constituents appear as isolated grains. In several of the latter class of meteorites (Farmington, Crab Orchard Mountains, Bluff) long, branching, metal filaments are seen to be associated with the isolated grains.

In the view of the present writer, these are filamentous phases of the structure of the metallic portions of the meteorite. Other meteorites, of which those of Honolulu, Mocs, and Pultusk may serve as illustrations, have what appear to be metallic veins when seen in cross sections. When cleft along the vein, however, these prove to be slickensided surfaces along which the metallic grains of the meteorite have been drawn or flattened out by the movement. These vein-like structures are clearly of different character from those just described. They sometimes give a well-marked appearance of a vein outlined on the crusted surface of a meteorite. This is owing to the fact that resisting fusion more than the stony matter they stand out in relief.

Cleavage and joints.— Most of the cubic irons are characterized by a complete cubic cleavage. This cleavage doubtless indicates that the masses are crystal individuals. Huntington has described cleavage planes as passing through some of the octahedral irons independent of the octahedral structure. It is probable that these, as well as cleavage along the octahedral planes often noted, are separation planes resulting from weathering.

Few stone meteorites are of sufficent size to exhibit a jointed structure if it existed. Meunier has called attention to an elongated depression in one of the L'Aigle stones which he regards as marking the position of a former joint plane. The Long Island meteorite, the largest stone meteorite known, is cut by three large division planes which perhaps represent joint planes. Two of them are at right angles to one another, while the third, somewhat broken, is nearly at right angles to the other two. The great irregularity of form of most meteorites,

however, would seem to indicate that division planes were lacking in the masses from which they have separated.

SYNTHETIC EXPERIMENTS IN THE REPRODUCTION OF STRUCTURAL DETAILS

Fouqué and Levy have succeeded in reproducing, so far as the component minerals were concerned, mineral aggregates corresponding to several types of meteorites. Among meteorites not containing feldspar, aggregates were produced corresponding to the meteorite of Rittersgrün, which is made up of chrysolite, enstatite, a magnesian pyroxene, and iron. Among meteorites containing feldspar, aggregates were produced corresponding to those of the class known as Eukrites, which are made up of anorthite, enstatite, and pyroxene, and of the class made up of anorthite, enstatite, and chrysolite. These were all produced by cooling from fusion, different mixtures of silica, alumina, magnesia, carbonate of lime and iron oxide. The chief difference noted by these authors between these products and meteorites of corresponding chemical composition is one of structure. The artificial products were of a marked granitoid texture, while most meteorites have as strongly brecciated or tuffaceous character. It is also true that the iron in the artificial products was in the form of oxide. This could, however, easily be reduced to the metallic state by exposing the mass to the action of reducing gas at a red heat for two hours. Previous to the experiments of Fouqué and Levy stone meteorites of several types had been fused by Daubrée and the resulting cooled products examined. The products resembled the original masses in some respects, but in many respects differed. Thus chrysolite and enstatite separated in a sort of liquation, the chrysolite forming a thin layer above, while the enstatite crystallized below in the form of long needles. Moreover the iron grains took spherical forms rather than the irregular ones which characterize meteorites. Daubrée therefore concluded that the mode of formation of meteorites differed from purely igneous fusion. The needles of enstatite artificially obtained

seemed analogous in his opinion to the needles formed on the surface of freezing liquids, while the grains seen in meteorites seem more like the forms of frost or snow formed by the immediate passage of water vapor to the solid state. This conclusion led to a number of experiments by Meunier with vapors of silica, magnesia, etc., for the purpose of forming in this manner if possible mineral aggregates resembling the meteorites The results so far obtained have been chiefly negative, though the experiments are still being conducted. A prominent feature lacking from the results of the experiments with vapors is the glass so abundant in meteorites. This is obtained in quantity however in the products cooled from fusion.

Many efforts have been made to reproduce Widmanstätten figures but they cannot be said to have met with much success. As it is held that the Widmanstätten figures indicate slow cooling from fusion, Sorby fused together iron, nickel, and other constituents of an iron meteorite, and allowed the mass to cool very slowly. On examining an etched surface with a lens, minute lines were seen which recalled the Widmanstätten figures but the appearance as a whole, he states, was very different. The mass was then kept for a long time at a temperature just below that of fusion but the resulting product was less like meteoric iron than that previously obtained. Daubrée fused a portion of the Caille meteorite in a crucible of clay, then allowed the mass to cool slowly. The resultant mass showed a crystalline structure but all trace of the former Widmanstätten figures was lost. On fusing a mixture of iron, nickel, troilite, and silica, he obtained a product showing dendritic figures. On fusing a mass of iron, nickel, and iron phosphate together, a mass having a reticulated structure with angles showing dodecahedral crystallization was obtained, The structure of this mass approached more nearly the Widmanstätten figures than any obtained in any other way, and it is sometimes stated that true Widmanstätten figures were produced. As Cohen remarks, however, the statement needs to be supported by figures and specimens. The same may be said of Meunier's

statement that he found Widmanstätten figures on a mass obtained by reducing iron and nickel chlorides from their vapors. J. Lawrence Smith states that he obtained Widmanstätten figures on a button of iron which cupelled from a mixture of iron silicate and chalk heated to fusion for from 15 to 20 minutes in oxygen in excess. If the excess of oxygen was essential to the success of this experiment, it was a condition certainly wanting in the formation of the iron meteorites.

It is true of chondri as of Widmanstätten figures that they have not yet been successfully reproduced by synthetic methods. Especially has it been found impossible to reproduce the structure exhibited by many enstatite chondri, of fibers radiating from a point eccentrically placed with reference to the center. Meunier has obtained from vapors of silicon chloride and magnesium acicular crystals of pyroxene which he recently showed the writer, which radiate in a fashion recalling the above-mentioned chondri. They cannot, however, be said to be in any sense reproductions of the chondri, and they are moreover a monoclinic pyroxene. Perhaps the nearest approach in form to these structures has been obtained recently by Brauns in crystals obtained by cooling sulphur. The forms were produced either by suddenly cooling a strongly heated preparation of sulphur or by slowly cooling and suddenly shaking it. Such results suggest that the peculiar structures of chondri indicate special conditions of cooling or percussion to which the mass has been subjected. If these conditions could be reproduced, chondri could, perhaps, be formed synthetically. It may be suggested that immediate contact with the intense cold of space, a condition which has not yet been experimentally fulfilled, is perhaps the force which has given chondri their peculiar form.

NOTE.—For further study and for lists of references the following works may be consulted: Meteoritenkunde, Heft I, E. COHEN, Encyclopedie chimique, Tome II, Meteorites, S. MEUNIER; Die mikroskopische Beschaffenheit der meteoriten, G. TSCHERMAK.

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EDITORIAL

A GEOLOGICAL and geographical excursion in the North Atlantic is planned for the summer of 1901. Conditionally on the formation of a sufficiently large party, a steamer of about 1000 tons, specially adapted for ice navigation, and capable of accommodating sixty men, will leave Boston on or about June 26 and return to the same point on or about September 20. The main object of the voyage will be to offer to the members of the excursion party opportunity of studying the volcanic cones and lava fields, the geysers, ice-caves and glaciers of Iceland, the fiords and glaciers of the west coast of Greenland, and the mountains and fiords of northern Labrador. Some attention will be paid to the hydrographic conditions of the waters traversed. Botanists, zoölogists, ornithologists, mineralogists, and those interested in other branches of natural history may pursue independent studies. A hunting party may take part in the expedition; it could be landed for a fortnight or three weeks in Greenland and for about the same period in Labrador.

An inclusive fee of $500 for each member will be charged, $250 to be deposited with the leader of the expedition on or before March 15, the balance to be paid or on before June 1.

The trip will be under the direction of Dr. R. A. Daly, of the Department of Geology and Geography, Harvard University, Cambridge, Mass. Applications for membership should be addressed to him.

Reviews.

Zeiller's *Flora of the Carboniferous Basin of Heraclea: An Illustration of Paleozoic Plant Distribution.*

At a meeting of the Biological Society of Washington in November 1897, the writer exhibited a small number of specimens of Carboniferous plants from Asia Minor, and called especial attention to the precise agreement in detail of several of the species with the corresponding types in our American Coal Measures. Particular emphasis was laid on the remarkable geographical distribution of plant species in Middle Carboniferous time, as to which the material in hand constituted new evidence. This striking agreement in exact form between the American and Asiatic species could not fail to arouse in paleobotanists the keenest interest in the publication of the results of the study of the southeastern flora by Professor Zeiller, to whose courtesy the writer was indebted for the above mentioned specimens.

Professor Zeiller's study of the Carboniferous flora of Heraclea[1] (Eregli) is an admirable example of stratigraphic paleobotany. To the stratigrapher who is unacquainted with the progress made of late years in the differentiation and recognition of the various Carboniferous floras of the Old World, and of their utility as means of correlation, it is an instructive illustration. To paleontologists this close, critical work is especially valuable for the light it throws on the areal distribution of identical species and on the identity and regularity in sequence of the floral associations characteristic of the several stages.

The fossil plant material, chiefly collected by M. Ralli, was obtained from several isolated areas in two of which the structure is particularly complicated, the terranes being diversely and frequently faulted, or even shattered. The collections from these areas are found by Zeiller to embrace 122 species which, when grouped by localities, very distinctly indicate three stages of the Carboniferous, which M. Ralli also is able to recognize stratigraphically in portions of the

[1] Étude sur la flore fossile du bassin houiller d'Héraclée (Asie Mineure). R. Zeiller, Mém. Soc. géol. Fr., Paléontologie, mém. 21, Paris, 1899, 91 pp., 6 pl.

territory, although the complex structure hardly admits of correlation without paleontological aid.

In the following paragraphs the general paleontological features of the three stages will be outlined, together with the correlations proposed by Zeiller. To this will be added comments on certain of the Heraclean plant types with some suggestions as to the relations of the Heraclean Carboniferous floras to those of eastern North America.

A. The lowest of the three paleobotanical stages recognized by Zeiller in the material examined is that of Aladja-Agzi. In the collections from several localities representing this stage in the various areas, he finds :[1]

Sphenopteris dicksonioides, S. bermudensiformis, S. Larischi,* S. divaricata,* Rhodea* cf. *Stachei, Diplotmema dissectum, D. elegans,* Adiantites oblongifolius,* Pecopteris aspera, Archæopteris,* sp., *Cardiopteris polymorpha, Sphenophyllum tenerrimum,* Asterocalamites scrobiculatus,* Calamites ostraviensis, C. ramifer,* Lepidodendron acuminatum,** and *Lepidophyllum lanceolatum.*

Two additional species are described as new, viz.: *Sphenopteris bithynica* and *Sphenophyllum Sewardi.*

Of the previously described species, all in the above list, with the exception of the undeterminable *Archæopteris* and the *Lepidophyllum lanceolatum* are also present in the Ostrau-Waldenburg (Upper Culm) stage of Silesia, with which the Aladja-Agzi flora is correlated by Professor Zeiller. The species marked by the asterisk (*) in the above list are also recorded from the Appalachian Pottsville, with whose lower portion the Ostrau-Waldenburg beds are probably, in part, at least, contemporary, as has already been elsewhere[2] indicated. Of the remaining plants *Sphenopteris bermudensiformis* is evidently closely related to a form from the Pottsville referred to *S. asplenioides*; while the specimens figured as *Diplotmema dissectum* appear to find a corresponding form in the latter formation. *Sphenopteris bithynica* seems to be extremely close to *S. subfurcata* Dn. from the supposed "Middle Devonian" [Pottsville] at St. John, N. B., while *Sphenophyllum Sewardi* stands in a similar relation to *S. tenue*[3] from the Welch

[1] The nomenclatural orthography in the following list is that used by Professor Zeiller.

[2] Bull. Geol. Soc. Amer., Vol. VI, p. 320, 1895. See also: Twentieth Annual Rept. U. S. Geol. Surv., Pt. II, p. 912.

[3] Twentieth Annual Rept. U. S. Geol. Surv., Pt. II, 1900, p. 900, Pl. CXCI, Figs. 6, 7.

formation (Middle Pottsville). With reference to the *Lepidophyllum lanceolatum* listed above, I would add that the specimen figured by Professor Zeiller would seem to agree with the *L. Campbellianum* described by Lesquereux from the Pottsville. The latter is much more slender, acute and narrowed toward the relatively small sporangiophore than is the quite distinct type, from the higher Coal Measures, identified by Lesquereux as *L. lanceolatum* L. and H. *Cardiopteris polymorpha* has not in this country been found in beds so high as the Pottsville, though it is present in beds of Chester age.

B. Above the Pero bed at Kilimli, whose flora belongs to the Aladja-Agzi stage, and separated from that bed by a conformable series of sandstones and conglomerates 90 meters in thickness lies the Sinork coal, with which are found *Mariopteris acuta, Asterophyllites grandis*, and *Lepidodendron Veltheimi.* The first two named are characteristic of the Westphalian of Europe, while the third is present in the Culm as well. The more exact place of this florula is in the lowest of the three stages of the Westphalian. All three species are present also in the lower group of the Kanawha formation in West Virginia. The plants accompanying the coals mined at Coslou (Kosloo) as well as those from a number of other localities, many of which are in faulted blocks, belong to the same stage as the Sinork plants, though some of the localities are evidently at a lower horizon in that stage than others.

The entire flora from this stage includes: *Sphenopteris obtusiloba**, *S. Schillingsi**†, *S. Baeumleri, S. Frenzeli, S. schatzlarensis, S. Sauveuri**†, *S. Crepini**†, *S. Laurenti**†, *S. Hoeninghausi**, *S. tenella**†, *S. Aschenborni, S. Schwerini, S. Karwinensis, S. Vüllersi, S. bella, S. Sternbergi, Rhacopteris subpetiolata, Palmatopteris furcata**, *P.* cf. *elegantiformis**, *Mariopteris muricata**†, *M. acuta**†, *Pecopteris plumosa**†, *P. aspera, P. pennæformis**, *Alethopteris Davreuxi, A. decurrens**†, *A. Lonchitica**†, *Lonchopteris Eschweileriana, Nevropteris gigantea**†, *N. Schlehani**†, *N. heterophylla**, *Sphenophyllum cuneifolium* (old form)*†, *Calamites Suckowi**, *C. undulatus**(?), *C. Cisti**, *C. ramosus**, *C. Schützei, C. distachyus, Asterophyllites grandis**†, *A. equisetiformis**, *Annularia galioides**, *A. Radiata**†, *Radicites columnaris**, *Lepidodendron lycopodioides, L. aculeatum**, *L. dichotomum**, *L. obovatum**†, *Lepidophloios laricinus**, *Lepidostrobus Geinitzi**, *Lepidophyllum lanceolatum**, *Sigillaria elegans**, *S. elongata**, *S. Schlotheimi**, *S. scutellata**, *S. Davreuxi**, *S. Boblayi, S. mamillaris**, *S. germanica, Stigmaria ficoides**, *Cordaites principalis**, *and Dorycordaites palmæformis.*

The new types described from this stage are *Sphenopteris Ralli, S. heracleensis, Potoniea adiantiformis, Calamophyllites vaginatus, Phyllotheca Ralli,* and *Sigillaria euxina.*

All but six of the species listed above are present in one or more of the European basins. The flora of the lower horizon is referred to the lowest of the three stages of the Westphalian, while that of the slightly younger horizon is regarded as overlapping on the lower or transition portion of the middle stage.

It is impracticable to discuss in this place the relations of the large and interesting flora from this stage to the floras of the United States. I have, however, marked with the asterisk (*) those species that are recorded from the Carboniferous of North America.

The percentage of identical species is undoubtedly fully as large as that marked in the list. Of the American representatives among the fern species the greater portion are present either in the Kanawha formation of southern West Virginia and Kentucky, or the upper portion of the Pottsville formation. In fact the flora of the lower horizon in the Coslou group is clearly comparable to the topmost Pottsville and earlier Kanawha plant associations. The flora of the upper horizon of the Coslou group has little in addition besides the Sigillarias that is common to the Allegheny series, and it, too, is distinctly older than that series, though it appears hardly so typical as the other flora of the Lower Kanawha group. The surprisingly close relations of the flora of the Coslou stage to the uppermost Pottsville, and particularly to the Lower Kanawha flora will be better understood when the detailed studies of the latter floras are published. Suffice it for the present to say that the species marked by the (†) in the above list are, so far as I have observed, peculiar to and characteristic of this combined portion of the Appalachian Upper Carboniferous section.

A few among the more important species closely related to American types deserve special mention: *Sphenopteris Vüllersi* is very close to a variety of *S. furcata* from the Southern Anthracite field; *S. Sternbergi* to *Aloiopteris* (*Sphenopteris*) *georgiana* of the Pottsville; and *Alethopteris Davreuxi* differs but little from the latest phase of *A. grandifolia.* My remarks on the *Lepidophyllum lanceolatum* in the lower stage probably apply equally to the Coslou specimens.

As *Potoniea* Zeiller describes a type of fructification whose fleshy adiantiform divisions are studded or fringed with fusiform bodies suggesting the sporangia of *Crossotheca* (*Sorocladus* of Lesquereux). It is

regarded by him as belonging more probably to a fern, though it is possibly gymnospermous. *Phyllotheca Ralli* is an extremely interesting type whose fructification appears to be very close to that of the living *Equisetum*, while the leaf sheath, suggestive of *Annularia radiata*, is very similar to that of an undescribed species from the lower Kanawha group of West Virginia. The genus *Phyllotheca*, which is present in the Indo-Australian *Glossopteris* flora (Permo-Carboniferous), and which for a long time was supposed not to have appeared in Europe until the Jurassic, has later been described from the Permian and is now known in the Coal Measures of both Europe and America.

C. The upper or Caradons stage in the Heraclean basins is represented by many localities whose largely common floras evidently lie in or near the same stage. Its flora includes: *Sphenopteris* (*Crossotheca*) *Crepini**, *S. Bronni**, *Palmatopteris alata**, *Pecopteris Miltoni**, *P. oreopteridia**, *P. unita**, *P. Roehli*, *P. plumosa**, *P. Pluckeneti**, *P. Newberryi**, *Alethopteris Serli**, *A. Grandini**, *Odontopteris britannica**, *O. Reichiana**, *Nevropteris Scheuchzeri**, *N. heterophylla**, *N. rarinervis**, *N. tenuifolia**, *Linopteris obliqua**, *L. Münsteri*, *Cauloptéris patria*, *Ptychopteris macrodiscus*, *Sphenophyllum cuneifolium**, *S. emarginatum**, *S. oblongifolium*, *S. majus**, *Annularia stellata**, *A. sphenophylloides**, *Lepidodendron Jaraczewski*, *Sigillaria tessellata**, *Cordaites borassifolius**, *Cordaites principalis**, *Cordaicarpus congruens**, and *Samaropsis fluitans**.

Five species, *Sphenopteris Limai*, *Pecopteris Armasi*, *Alethopteris pontica*, *Linopteris elongata*, and *Plinthiotheca anatolica*, have not been found elsewhere.

In the above list the asterisk (*) denotes an American distribution for the species, most of which are familiar to those geologists who have observed the plants of the Coal Measures in the northern bituminous basins. Among them *Pecopteris Miltoni*, *P. unita*, *P. Pluckeneti*, *P. Newberryi*, *Alethopteris Serlii*, *A. Grandini*, *Odontopteris britannica*, *O. Reichiana*, *Nevropteris Scheuchzeri*, *N. rarinervis*, *Linopteris obliqua*, *Sphenophyllum emarginatum*, *S. oblongifolium*, *S. majus*, *Annularia stellata*, *and A. sphenophylloides* are characteristic of the Allegheny series and higher Coal Measures.

The flora of the Caradons stage contains a mingling of uppermost Westphalian species with Stephanian types. This flora is correlated by Zeiller with that of the stage of the Radstock Series in England, the Geislaütern beds in the Saar region, the "middle series" in the

Zwickau basin of Saxony, the Schwadowitz beds in lower Silesia, and with the Mazon Creek, Illinois, flora of the United States.

The flora of Mazon Creek seems to find its place in the Kittanning group of the Pennsylvania basins, and probably near the horizon of the Middle Kittanning coal. The presence of certain species, particularly of *Odontopteris*, of abundant *Linopteris obliqua*, of *Pecopteris Miltoni*, of *Alethopteris Grandini*, and of *Sphenophyllum oblongifolium* in the Heraclean flora leads me to conclude that the Caradons material was derived from beds slightly later than the Mazon Creek horizon, or perhaps as high as the Freeport group, which is next above the Kittanning group, though also within the Allegheny series. *Sphenopteris Crepini*, which is probably present in the upper Kanawha group, is very closely related to *Sphenopteris sagittata* from Mazon Creek and *S. ophioglossoides* from the Des Moines series of Missouri. *Sphenopteris Bronni*, *Nevropteris tenuifolia*, *Sphenophyllum cuneifolium* and *Cardiocarpus congruens* are perhaps the only species whose presence in the Caradons flora argues, on the one hand, for a horizon lower than that of Mazon Creek. The far more important and abundant evidence of the fern elements is, on the other hand, for a rather later date.

The most interesting of the plants newly described from the Caradons beds are *Pecopteris Armasi* and *Plinthiotheca anatolica*. The former appears to form a connecting link between *Pecopteris* and *Callipteridium*. *Plinthiotheca* is represented by thick, fleshy peltate or cyclopteroid leaves, radiately densely vascular and covered by small capsules arranged in fours in contiguous squares. These capsules are regarded by Professor Zeiller as sporiferous, rather than polleniferous; and the type is therefore tentatively ranged by him with the ferns instead of with the Doleropteroid gymnosperms. The examination of Zeiller's figures and a careful comparison of the types of *Dolerophyllum pennsylvanicum* in the Lacoe collection convinces me that the Heraclean type is generically identical with that described from Pennsylvania by the late Sir William Dawson.[1]

The generally close agreement mutually between Professor Zeiller's correlations of the Heraclean floras in Europe or this country with my own correlations of the Middle Pottsville, the Lower Kanawha, and the Allegheny series well illustrates the marked paleobotanical differentiation of the stages, and the regularity of the sequence, as well as the extraordinary geographical distribution of the several Middle

[1]Can. Rec. Sci., Vol. VI, p. 8, 1890.

Carboniferous floras. Of the 122 species contained in the collections from the three Heraclean stages not more than eleven are unknown in Europe or America.

DAVID WHITE.

Géologie et minéralogie appliquées. Les minéraux utiles et leur gisements. Par HENRI CHARPENTIER. Pp. 643 + xi; illustrated, 12mo. Paris, 1900.

This volume forms a part of the *Bibliothèque du Conducteur de Travaux Publics* of France, and is published under the auspices of the ministers of public works, of agriculture, of public instruction, of commerce and industry, etc. Its title-page is followed by the *Comité de patronage*, a list of thirty-nine prominent government officials, and by the editing committee with twenty-seven additional and equally distinguished names; then comes a preface written by the chief engineer of mines.

A work upon economic geology, introduced with these impressive formalities and distinguished approvals, one naturally expects to find of unusual merit and importance. The general plan of the work is very like that followed by Fuchs and De Launay in their large and excellent *Traité des Gîtes minéraux et métallifères*, published in 1893; but this work by Charpentier is evidently intended to be more elementary and for a less instructed class of readers.

The first seventy-four pages are devoted to general geology, mineralogy and paleontology. In the second part the economic-geologic subjects are taken up in the following order:

(1) Building materials, (2) Metallurgical minerals, (3) Carbon and its compounds, (4) Fertilizers, (5) Miscellaneous minerals, (6) Rare metals, (7) Precious stones.

These topics are properly subdivided and treated separately, and at the end of each discussion is a list of bibliographic references that varies in length from one to thirty or more titles chronologically arranged. The economic geology of France naturally occupies the first place, but those of other countries are also treated at such length as to lead one to suppose that the book was expected to be useful outside of France.

The bibliography given after each topic will appeal to busy readers as especially useful. In the preface it is stated that this *bibliographie fort complète* will do away with tiresome searching for literature by

those who want to go deeper into the subjects treated. We venture to hope that the busy reader will be more fortunate in the use of these references than we have been. To one somewhat acquainted with the general literature of economic geology these lists are more remarkable for what they do not than for what they do contain. What must geologists and mining engineers in any part of the world think of bibliographies with such omissions as the following? Under Building Stones no reference is made to Merrill; under Copper no mention of Whitney, Irving, or Wadsworth; under Zinc no mention of Winslow; under Phosphates and Manganese no mention of Penrose; under Quicksilver no reference to Becker; under Petroleum and Natural Gas no mention of Carll or Orton; under Silver no reference to Emmons; and under Diamonds no mention of the writings of Derby.

The references that are given are often quite irrelevant, and sometimes wrong. For example under the list upon "combustible minerals," p. 405, is this: "1871. Hartt. *La faune carboniferienne du Missouri* (Neues Jahrb., p. 63)." The place cited contains a note by Louis Agassiz upon the Carboniferous fauna found by Hartt in South America. There is not a word about Missouri, and as a matter of fact there is no coal in the South American Carboniferous area mentioned by Hartt. On p. 406 is this: "1878. Derby. *Le carboniferien au Missouri* (Neues Jahrb., p. 663)." There is no such article at the page cited, and I much doubt Professor Derby's having written such an article at all. On p. 538 the bibliography of kaolin gives a title by Fontannes. Upon looking up the article cited it is found to contain nothing about kaolin. In addition to these defects the typographical errors in the references render many of them worthless.

The book seems to be intended for a sort of *vade mecum* on economic geology, and as such it will be found helpful. It is of convenient size and neatly bound in flexible leather.

J. C. BRANNER.

Handbuch der Seenkunde. Allgemeine Limnologie. Von DR. F. A. FOREL. Stuttgart: Verlag von J. Engelhorn.

This volume is one of the series of useful geographic handbooks published under the general editorship of Professor Dr. Friedrich Ratzel. It brings together in concise, comprehensive, and readable form the general principles of limnology.

The first part of the volume is devoted to a discussion of lake basins, the discussion covering the origin of lake basins and of lakes, the obliteration of the basins, and the deposits made in them.

The second and larger part of the volume deals with the waters of lakes. Here are included (1) Hydrology — supply and waste; (2) Hydraulics, including the pressure of the water, the levels of lakes, their changes, permanent and temporary, rhythmic and non-rhythmic, the waves, seiches, currents, etc.; (3) Chemistry, including the comparative study of the waters flowing into the lakes, that in the lakes, and that flowing from them. Comparisons are also made with sea water; (4) The temperature of lakes, including a discussion of surface temperatures, their areal and periodic variations, comparisons of the temperature of the surface water with that of the overlying air, and the temperature of the sub-surface waters; a section is also given to the freezing of the lake water; (5) Optics, including the penetration of light, the color of the water, reflection, refraction, etc., under various conditions; (6) The biology of lakes. Besides the more obvious topics considered in this chapter, a section is given to the origin of lacustrine societies, and another to the physiology of lacustrine organisms.

In an appendix is given an outline for the prosecution of lacustrine studies, and also a bibliography.

The volume is the best brief compendium on the subject with which it deals. R. D. S.

A Preliminary Report on the Artesian Basins of Wyoming. Bulletin 45 of the Wyoming Experiment Station. By WILBUR C. KNIGHT.

While this report is primarily a consideration of the artesian basins of the state, its first part is devoted to a summary of existing knowledge concerning the geology of the state. The following systems of rocks are represented: Archean, Algonkian, Cambrian, Devonian, Carboniferous, Permian, Triassic, Jurassic, Cretaceous, Eocene, Oligocene, Miocene, and Pleistocene.

The Archean is found at various points in the mountain ranges. The Algonkian has a similar distribution, with a total maximum thickness, including some igneous rock, of 20,000 feet. Following the deposition of the Algonkian rock were great disturbances and elevations, followed by a prolonged period of erosion. The late Cambrian

and late Ordovician periods are represented by relatively thin formations, chiefly of limestone. The Ordovician is found only in the northern part of the state, and the Devonian, so far as now known, only in the northwestern. As elsewhere in this part of the United States, the Devonian seems to rest conformably on the Ordovician. The Carboniferous is more fully represented than the preceding systems. The Lower Carboniferous is found only in the northern half of the state, while the Upper is more widespread. Limestone is the dominant rock. The Permian occurs in the Laramie, Big Horn, and Wind River mountains. It has but slight thickness, 200 feet or so, but has the fauna characteristic of the period.

The Mesozoic systems are much more fully represented, being in the aggregate 20,000 to 30,000 feet thick. They are in general conformable on the Paleozoic.

The Triassic system is represented by the Red Beds, which are gypsiferous and without fossils. The Jurassic system is represented by a marine division, the Shirley formation, overlaid by a fresh-water division, the Como formation. Both formations are referred to the later third of the Jurassic period. No special reasons are given for assigning the Como to the Jurassic, rather than to the Lower Cretaceous. This formation is said to have covered most, if not all of the state, and its character is such as to indicate marshy and lacustrine conditions.

The Cretaceous formations are the most extensive in the state. They cover about 50,000 square miles, and the thickness is 20,000 to 25,000 feet. The following formations are present: The Dakota, Bear River, Fort Benton, Niobrara (which contains some chalk), the Fort Pierre and Fox Hills formations, which together are, at the maximum, something more than two miles thick, and the Laramie, which has a thickness of about one mile. The Montana division (Fort Pierre and Fox Hills) contains some oil and coal, and the Laramie much coal. The Fort Union beds are also placed with the Cretaceous, with a question.

The areas of the Tertiary rocks are characterized by the Bad Land topography. The Eocene is represented by the Bridger, Green River, and Wasatch beds; the Oligocene by the White River beds; the Miocene by the Loup Fork. The Eocene beds have an aggregate thickness of 3500 feet, the White River of 1500, and the Loup Fork of 500. Pliocene beds are not known.

During the Pleistocene there were very considerable glaciers in the Wind River, Absaroka, Shoshone, Big Horn, and Medicine Bow mountains, as well as in the Yellowstone Park. Glaciers also reached the state line from the Uinta Mountains. No subdivisions of the glacial period have been made out.

The report is accompanied by an uncolored geological map, which is, we believe, the first geological map of the state which has been published. R..D. S

Die vierte Eiszeit im Bereiche der Alpen, von ALBRECHT PENCK. Vorträge des Vereines zur Verbreitung naturwissenschaftlicher Kenntnisse in Wien. XXXIX. Jahrgang. Heft 3, 1899.

In this little pamphlet, as the title implies, Dr. Penck recognizes four distinct epochs of glaciation (instead of three as heretofore) in the Alps. The additional epoch which is here added belongs to the earlier rather than to the later stage of the glacial period. The differentiation of these several epochs is based primarily on the topographic distribution of the deposits made by the waters which flowed from the ice, the deposits of the several epochs being so disposed as to show very considerable periods of erosion between the periods of fluvioglacial deposition.

This paper is of interest in that it helps to bring the phenomena of this somewhat isolated area of glaciation into still closer correspondence with the phenomena of the greater areas of glaciation in northwestern Europe and North America.

R. D. S.

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